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ECOSYSTEMS ANALYSIS OF THE BIG CYPRESS SWAMP AND ESTUARIES

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16. Abstracts
The U. S. Environmental Protection Agency (EPA) conducted a two year study to obtain necessary biological and hydrological information for objective planning of wise use of south Florida's land, water, wildlife and fisheries resources. Field investigations during 1971-1972 intensively examined the details of biotic community interactions with hydrologic conditions of disturbed and relatively unaffected regions of the Big Cypress Swamp and contiguous tidal wetlands and estuaries. Process studies and experimental manipulation models were formulated for the various components of the ecosystem.

Study results demonstrate the total dependence of the South Florida ecosystem on the hydroperiod. Canal drainage of upland wetlands which include cypress swamps and wet-prairies effected a 10 fold decrease in primary productivity. Drainage also effected a thinning of the forest canopy and induced a reduction in the rate of forest litter decomposition resulting in a buildup of litter as increased fuel sources for destructive wildfires.

Canal drainage of uplands also effected the estuaries resulting in changes in the benthic plant communities, increased nutrients, increased metals in sediments, and a change in the abundance and diversity of fishes.

For the first time, tidal streams were proven to be a major nursery area for young snook.

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FOREWORD

This report and the study it represents are replete with examples of the sensitive and interdependent relationships necessary for survival of south Florida's natural ecosystem. It is hoped that readers of the report will include planners, government officials, land developers and/or owners, concerned citizens, as well as the ecologists and scientists interested in the technical findings presented. Environmental protection is a complicated task and it will take an educated public to understand it and make it work. Even though part of a whole -- the multiagency South Florida Environmental Project -- EPA's study findings can still be used to draw specific recommendations. The reader may be able to suggest more as he reviews the more detailed chapters.

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I - SUMMARY

Because of environmental considerations which arose when the Dade County Port Authority began construction of a 39 square mile jetport on the eastern edge of the Big Cypress Swamp, the U. S. Department of the Interior initiated the South Florida Environmental Project. This multiagency effort was designed to provide information for Federal, State and local decision makers in south Florida to use in determining the best utilization of all area resources. The overall objective of the U. S. Environmental Protection Agency's (EPA) role in this study was to obtain necessary technical information for objective planning of a program of wise use of south Florida's land, water, wildlife and fisheries resources. The strategy selected by EPA was to obtain detailed technical knowledge of the intricate interrelationships existing among the various components of disturbed and relatively unaffected (by human activity) ecosystems. This knowledge would then be used to formulate process studies and experimental manipulation models for the various components of the ecosystem.

In order to accomplish the stated objectives, an in-depth study of a representative area of the Big Cypress Swamp was conducted. The selected study area was Fahkahatchee Strand (Figure V-3) and contiguous areas in Collier County, including the bays and estuaries to the southwest. Field investigations during 1971-1972 intensively examined biotic community interactions and were concentrated on paired sites located within the Fahkahatchee Strand ecosystem and contiguous tidal wetlands and estuaries with both contrasting natural and hydrologically-disturbed ecosystems.

EPA assembled a team of scientists consisting of engineers, systems ecologists, fishery biologists, freshwater biologists, botanists, chemists and technicians to conduct the study. Offices and chemical and biological laboratories were established at the Rookery Bay Marine Station located between Naples and Marco Island. Additional technical support was obtained from the Chemical Services Branch and the Biological Services Branch, Surveillance and Analysis Division, EPA Region IV, in Athens, Georgia, and EPA's National Field Investigations Center at Cincinnati, Ohio.

BACKGROUND

Unprecedented growth has taken place in the Collier County portion of the Big Cypress Swamp during the last decade. From 1960 to 1970, Collier County was the fifth fastest growing county in the United States with a population increase from 15,753 to 36,568, or 132 percent. County planners expect the population to reach 200,000 - 250,000 by the year 2000. Detrimental results from this population increase on the environment is evident, especially in the highly important estuarine areas. Onetime highly productive areas are now being drained and mangrove forests cleared and filled for homesites and commercial developments. Tidal streams have ceased to flow because of bulkheads. Public access to many beaches has been blocked by oceanfront condominiums and apartments.

PHYSIOGRAPHY

The study area elevation is less than four meters above mean sea level and land slopes gently south to southwest, varying from 8 to 16 cm/km. Natural drainage of the land is slow and sheet flow occurs during much of the year, especially during the hydroperiod. Geologically, the area is underlain by Tamiami limestone of Miocene age. Soils of pure sand, marl or mixtures of both with layers from 5 to 60 centimeters deep rest on the irregular surface of the limestone. Peat muck fills the depressions in the bedrock.

CLIMATOLOGY

Most rainfall within the basin is of high intensity and short duration, and the presence of artificial channels leading to tidewater effectively exports much of this rainfall before maximum infiltration can occur.

During 1972, rainfall in Fahkahatchee Strand averaged 142 centimeters and ranged from 120 to 194 centimeters. Maximum daily rainfall of 11.75 centimeters occurred on June 19, 1972, during Hurricane Agnes. Rainfall occurred on 168 days during 1972. Air temperatures ranged from 4°C to 36°C with a yearly average of 23°C. Relative humidity ranged from 30 to 100 percent with an average of 83 percent.

Evapotranspiration is a major consumptive user of groundwater in south Florida. Depending upon the time of the year, evapotranspiration may account for 90 to 95 percent of the groundwater drawdown in areas unaffected by drainage canals. During 1972, pan evaporation in the study area averaged 139.5 centimeters with solar energy ranging from a low of 270 langleys/day in December to a high of 745 langleys/day in June.

HYDROLOGY

Surface flows throughout 1972 were less than flows recorded during the previous two years. No measurable surface water entered Fahkahatchee Strand from above Alligator Alley during 65 percent of the year and no measurable flow crossed Janes Scenic Drive 45 percent of the year despite higher than average rainfall. With the exception of eight days in June, the main slough in Fahkahatchee Strand was essentially void of surface water from April 1 until August 27. The maximum area of inundation occurred in November, when approximately 51 percent of the study area north of U. S. 41 was inundated.

Based on historical rainfall information, calendar years 1970 and 1971 were substantially below normal, but freshwater export from the Strand to its dependent estuary continued at near-normal rates. Calendar year 1972 was above normal in rainfall, but surface water export from the Strand virtually ceased. This lack of water export in itself is no cause for alarm and may represent a natural cycle in which the upland ecosystem functions as a reservoir to maintain brackish water conditions in the estuarine zone. Wet-dry conditions are essential to full productivity of the estuarine ecosystem. However, contrary to expectation, groundwater tables in the upland zone failed to recover from the depressed levels present at the end of the 1970-71 dry period, despite rainfall inputs in 1972 well above long-term mean values. Drainage canals prevented recovery of groundwater levels. These canals had a catastrophic effect on groundwater levels -- lowering natural levels as much as 122 centimeters. Maximum recession rates in the vicinity of canals were measured at 9.1 to 10.4 cm/day compared with 2.1 to 4.0 cm/day in areas unaffected by the canals. Groundwater levels throughout the study area were below normal during most of the year. The maximum water level drawdown below the surface was 1.79 meters in the vicinity of canals and 1.42 meters in locations not influenced by canals. Direct groundwater drainage by canals was measured as high as 588 l/sec/km (31.7 cfs/mile). Groundwater gradients of 14.2 cm/km were found to be typical in a north-south direction in Fahkahatchee Strand compared with 25.5 cm/km in an east-west direction near the easternmost GAC canal.

Fahka Union Bay, which receives massive discharges of freshwater drainage from the Fahka Union Canal had salinity variations much greater than those of Fahkahatchee Bay which receives natural runoff. During August, 1972, salinities ranged from 27 to 32 ppt in Fahkahatchee Bay compared with 11 to 29 ppt in Fahka Union Bay. Average salinities were always higher in Fahkahatchee Bay than in Fahka Union Bay.

SEDIMENTATION

Fahkahatchee and Fahka Union Bay bottoms were found to be predominantly mud, 52 and 76 percent, respectively, with sand blending to a lesser extent. Oyster bars appear in isolated locations in both bays.

Sedimentation studies revealed mean rates of 126 and 160 gm/m^2/day, the greatest mean rates being in Fahka Union Bay. However, when these rates were normalized for depth, the sedimentation rates for both bays were relatively equal, indicating that resuspension of unconsolidated deposits was the principal variable measured by this technique. Organic content of sediment deposits decreased with depth.

DETRITAL TRANSPORT

Detritus entered Fahkahatchee Bay from salt marshes and mangrove forests via tidal creeks and rivers at the rate of 9,000 Kg carbon/day in mid-October, 1972. At the same time, Fahkahatchee Bay released nearly 13,000 Kg carbon/day into the Gulf of Mexico. Therefore, 4,000 Kg carbon/day came from the bay itself. Ninety-five percent of the particulate organic carbon entering Fahkahatchee Bay via the tidal rivers was found to be less than 0.8 micron in size. A seasonal decrease in concentrations of total organic carbon (TOC), tannins and lignins occurred from July to October. The quantity of organic carbon entering Fahka Union Bay on an ebb tide was 2 to 14 times the quantity entering Fahkahatchee Bay based upon mass per unit of bay area. However, a majority of the organic carbon which entered Fahka Union Bay was "short circuited" into the Gulf by the relatively deep Fahka Union Canal that transects this bay.

WATER CHEMISTRY

Fourteen physical and chemical water quality parameters were analyzed monthly from sixteen stations:

- Temperature
- Turbidity
- Apparent color
- Conductivity
- pH
- Alkalinity
- Chlorides
- Dissolved Oxygen
- Total and soluble Kjeldahl nitrogen
- Nitrate and nitrite nitrogen
- Total and soluble organic carbon
- Total and soluble phosphorus
- Sulfate
- Tannin and lignin "like" compounds.

Surface waters in Fahkahatchee Strand consistently had greater concentrations of total phosphorus, total organic carbon, total Kjeldahl nitrogen, apparent color and tannin and lignin "like" compounds than did the drainage canals. Alkalinity, dissolved oxygen and turbidity were higher in the canals. However, due to the large flows in the drainage networks, the quantities of nutrients transported by the Fahka Union Canal were much greater than those transported across Janes Scenic Drive (five times more total Kjeldahl nitrogen, ten times more total phosphorus, and seven times more total organic carbon). Rainfall and flow variations produced annual trends in many of the water quality parameters. During the wet season (summer and fall), tannin and lignin "like" compounds and nutrient concentrations increased. During the dry season (winter and spring), conductivity and chloride values increased.

Ten metals and 24 pesticides which have common use in south Florida were monitored quarterly in water, sediment and biota. In some cases the median concentration of metals found in the sediment of borrow canals was four to five times greater in the developed areas than in the undeveloped areas. The concentration of all metals found in the sediment of Fahka Union Bay was at least twice that observed in Fahkahatchee Bay. However, the water column in Fahkahatchee Bay contained greater concentrations of metals than did Fahka Union Bay.

Surface waters within the study area were free of detectable levels of pesticides. In the sediments, only DDT, DDD, DDE, and PCB's were detected with any significant frequency. The highest concentrations of DDT, DDD, and DDE were 160, 160, and 96 ug/Kg, respectively, and were observed during January, 1972, in sediments of the Barron River Canal which drains a portion of the agricultural area near Immokalee known as the Okaloacoochee Slough.

Only six pesticides (DDT, DDD, DDE, PBC's, Dieldrin, and Myrex) were observed in biotic samples. With the exception of DDT in the Florida gar and in an Atlantic bonito, the detected levels of the above mentioned pesticides were generally less than 50 ug/Kg (wet wt). The most probable source of these compounds was upland agricultural runoff.

PRIMARY PRODUCTION

Studies of primary productivity were conducted on the benthic plant communities inhabiting Fahka Union and Fahkahatchee Bays. Gross primary productivity was determined with the use of benthic respirometers. Estimates of net productivity were established from plant community biomass accumulation rates measured over the sampling year with plant harvesting techniques. Results of these studies show that Fahka Union Bay maintained a benthic plant community comprised mainly of green filamentous algae, *Rhizoclonium hookeri*, and red macroalgae, *Gracilaria* spp. and *Dasya harveyi*. This algal community sustained an average gross primary productivity of 0.24 gm C/m^2/day for the year. Over the same period, net productivity in terms of biomass accumulation was 0.17 gm dry wt/m^2/day. Marked increases in primary productivity occurred concurrently with seasonal flushing of nutrients into the bay from upland sources via Fahka Union Canal.

Fahkahatchee Bay supported a benthic seagrass community composed primarily of *Diplanthera wrightii*, with some *Thalassia testudinum*, and *Halophila engelmannii*. Gross primary productivity of the community followed a slight but steady decline through the sampling year with an average rate of 0.20 gm dry wt/m^2/day.

Gross primary productivity was obtained for salt marsh and mangrove communities along a decreasing freshwater gradient. Diel metabolic rates were determined from field measurements of carbon dioxide uptake and release by plant components isolated in clear plastic metabolic chambers. Metabolic measurements in the salt marshes were limited to the emergent portions of the marsh plants. Gross productivity of the salt marsh community increased with a reduction in fresh water availability and concomitant decrease in the number of plant species inhabiting the marshes. Based on the measured increase in the ratio of 24-hour respiration to gross primary productivity, and in the chloride concentrations, the reduction in the number of marsh species appeared related to the effects of metabolic stress caused by increased salinity.

Mangrove tree gross productivity also responded to a freshwater concentration gradient that ranged from a minimum of 4.7 ppt to a maximum of 16 ppt chlorides. Gross metabolism of red mangrove leaves, *Rhizophora mangle*, decreased steadily with increasing levels of chlorides. In contrast, leaf gross productivity of the black, *Avicennia nitida*, and white, *Laguncularia racemosa*, mangrove species increased in response to greater chloride levels. Total mangrove red, black and white community metabolism, trees only, responded to a decreasing gradient of freshwater concentrations in the following manner: gross productivity increased, respiration increased, and net productivity decreased.

Mean surface water chlorides (ppt)	Mangrove community metabolism (gm C/m^2/day)		
	GPP	NPP	R_{24}
4.7	10.3	6.6	3.7
12.7	11.8	7.5	4.3
16.0	13.9	4.8	9.1

The effects of land drainage systems on annual increases in standing crop biomass of a cypress forest community were assessed. Dramatic differences in standing crop biomass were evident between drained and undrained regions of the cypress forest. Combined biomass of trees, shrubs, and herbs averaged nearly 9 kg dry wt/m^2 in the drained region while the undrained area supported a similar community type with a combined standing crop biomass averaging 17 kg dry wt/m^2. The net gain in community biomass for the sampling year averaged 3.1 gm dry wt/m^2/day and 0.31 gm dry wt/m^2/day for the undrained and drained regions, respectively.

Litter accumulation on the forest floor in the cypress sites was assessed. The undrained region showed an annual accumulation of 374 gm dry wt/m^2 compared to 267 gm dry wt/m^2 in the drained area (all values corrected for losses to decomposition). Leaf turnover rate in the undrained region was 0.791 turnovers per year vs 1.035 turnovers per year in the drained area. Thus, the canopy in the drained area is subject to thinning. Relatively large leaf-fall rates in the drained area produces greater sunlight penetration and, with the abnormal lack of surface waters, create a large stock of highly flammable materials on the forest floor.

Preweighed parcels of litter (leaves, stems, etc.) were placed on the forest floor to determine the effects of microclimatic conditions on litter decay over a 12 month period. Results of this study show that the remineralization of litter proceded at a reduced rate under drained conditions in the cypress forest.

PLANT SOCIOLOGY

One of the most striking features of the plant communities in the study area was the broad range of habitats present and the great species richness of the area. Within each habitat, generally more than 20 plant species occurred frequently enough to be considered common.

The cypress strand contained some 23 common species of woody trees and shrubs, 17 species of common vines, 28 species of common terrestrial herbs, 18 species of common epiphytic herbs, and 15 species of common aquatic vascular plants including a few macroalgae. The wet prairies, which seem at casual glance to be monocultures of grass, in fact contained 28 species of common monocots and 36 species of common dicots. The pine and palm association contained some 13 species of common woody trees and shrubs, and 33 species of common herbs. Ditches and canals contained some 34 common aquatic plant species. Even roadsides adjacent to prairies and cypress strands contained over 28 common species of plants. Strands, lakes and ponds contained 23 species of common aquatics. The mangrove swamps contained, in addition to four species of common trees, 25 species of common herbs, three species of common lianas and several species of epiphytic herbs. Not included above are the many rare and exotic plants.

FISH

Investigations of the fish fauna of Fahkahatchee Strand and the Ten Thousand Islands were directed toward acquiring base line estimates of the absolute abundance (standing crops of fishes) of freshwater and estuarine fish populations and on the relative abundance of estuarine fishes.

Estimates of the fish populations were obtained monthly at two sites in Fahkahatchee Strand with a square meter frame and rotenone. Distribution and abundance of the fishes in the freshwater areas of Fahkahatchee Strand were directly related to the cyclic nature of the hydroperiod. The lowest number and biomass of fish occurred during the wet summer and fall periods, whereas the largest number and biomass occurred during the dry winter and spring months when the fishes were concentrated in small ponds and sloughs.

Single estimates of fish populations were taken at ten other locations with either block net and rotenone or an enclosed net and seines. The biomass estimates for the fish populations were as follows:

- Natural Lake in Fahkahatchee Strand - 14.1 gm/m^2
- GAC Canal - 6.6 gm/m^2
- Tamiami Canal - 170.7 gm/m^2
- Three sites in Fahka Union Bay - 0.7, 2.2, and 14.3 gm/m^2
- Three locations in Fahkahatchee Bay - 9.3, 1.4, and 6.3 gm/m^2, and
- A tidal stream in north Fahkahatchee Bay - 89.8 gm/m^2.

During the year, a total of 273,270 fishes, representing 96 species and 41 families, were taken in seines, surface trawls and other trawls at 14 stations. Their total biomass was 414.3 kg.

By number and biomass, the dominant species in the regular catches were the anchovies, primarily the bay anchovy (Anchoa mitchilli). Excluding the anchovies (Anchoa spp.), the most abundant fishes by number were yellowfin menhaden (Brevoortia smithi), scaled sardine (Harengula pensacolae), pinfish (Lagodon rhomboides), silver perch (Bairdiella chrysura), and silver jenny (Eucinostomus gula). However, ranked by biomass, the dominant species were southern stingray (Dasyatis americana), scaled sardine, fantail mullet (Mugil trichodon), striped mullet (M. cephalus), and silver perch.

Analyses of the catches from the relative abundance and standing crop studies showed that a greater abundance and diversity of fishes existed in Fahkahatchee Bay, a relatively undisturbed environment, than in Fahka Union Bay, a disturbed estuary. The composition of benthic fishes and the types of bottom vegetation differed between bays. Abundant benthic fishes, such as pinfish and silver perch, inhabited the dense stands of grasses (Thalassia and Diplanthera) in Fahkahatchee Bay, while these grasses and their associated fishes were scarce in the other bay.

A total of 193 juvenile snook (Centropomus undecimalis) were seined from tidal streams in the Ten Thousand Islands between November, 1971, and December, 1972. These juveniles ranged in size from 14.0 to 196.0 mm fork length (anterior extremity of closed jaws to the tip of the rays in the center of the caudal fin). Most individuals (94.8 percent) were members of the 1972-year-class.

For the first time, tidal streams were proven to be a major nursery area for young snook. Shallow brackish stream habitats provided an abundant supply of small forage organisms, flowing water, low salinities, favorable water temperatures, and the general absence of piscivorous predators.

The growth rate of juvenile snook was approximately 1 mm per day during the warmer months. This estimate was based on the size of the juveniles at the time of collection in conjunction with the duration of the spawning season. By the end of December, a few individuals of the 0 age-class had attained a length of 200 mm FL.

Stomach analyses of 183 juvenile snook (142 contained food) indicated that the main food items, by volume, were fishes (81 percent), shrimps (16 percent), crabs (2 percent), with lesser amounts of zooplankton and immature insects. Dominant forage fishes were poeciliids, cyprinodonts, and atherinids. Feeding intensified in moving water following a slack tide.

As a function of growth, juvenile snook exhibited two distinct feeding stages. Smaller juveniles (< 20 mm FL) were exclusively planktivorous. A mixture of food items, consisting of zooplankton, fishes, and palaemonid shrimp, were consumed during a transitional period between 21 to 25 mm in length. Larger juveniles (>26 mm FL) acquired a carnivorous diet (mainly piscivorous).

On a volumetric basis, the summer diet of 271 adults (142 stomachs contained food) consisted of fishes (55 percent), crabs (32 percent), and shrimps (10 percent). Peaks in feeding intensity generally occurred from sunset to sunrise in conjunction with moving water.

WASTE INVENTORY

Current waste treatment practices and disposal methods for southwest Florida were inventoried. Of the 309 facilities inventoried, 88 percent were of a design capacity of less than 50,000 gpd, mostly package plants. Most plants provided the equivalent of secondary treatment.

II - CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The potential consequences of poor surface water conservation practices have serious economic as well as ecological implications. The apparent superabundance of water in south Florida is a pernicious illusion. Without adequate water reserves, the inevitable series of low rainfall years will impose economic hardships on the human population of south Florida. Effective surface water control schemes should involve the utilization of natural ecological systems, which incorporate water conservation "practices" as part of their normal functioning. Use of the natural system should be an integral part of any comprehensive conservation or development planning.

The effects of drainage works on Big Cypress regional ecosystems can be summarized in terms of hydrologic variables and entrained influences on the structure and metabolism of biological communities.

1. With favorable climatic conditions, recreational opportunities, and availability of suitable home sites, Collier County will continue its rapid rate of growth. However, the quality of the county land and water environment will deteriorate at an accelerating rate as population pressures are applied to the existing ecosystem of south Florida.

2. During 1972 rainfall was the major source of water input into the Fahkahatchee study area. Overland flow entering the study area was negligible.

3. Evapotranspiration was the major source of water export from the study area (76.6 percent during 1972), followed by canal export, surface flow and subsurface flow.

4. Groundwater recession rates were approximately four times greater in the vicinity of canals than in an undrained area. As designed, canals remove surface waters efficiently and rapidly and lower the groundwater table. Canals alone cannot maintain higher than natural groundwater levels. Nearly two million people (based on 100 gallons per person per day) could have been supported on the quantity of fresh water discharged by the Fahka Union Canal during 1970-1972. Discharges from drainage canals had a pronounced effect on salinity patterns within the estuaries. Bays receiving upland drainage via canals had lower salinities than did natural bays.

5. Mud is the primary substrate of the majority of the Ten Thousand Islands Bays. Sedimentation rates were greater in Fahka Union Bay than in Fahkahatchee Bay. Fahka Union Bay was more susceptible to substrate resuspension due to its shallowness. The topography of Fahkahatchee Bay is significantly different than Fahka Union Bay in that the latter bay is 30 percent shallower and has only 25 percent of the area of Fahkahatchee Bay.

6. The volatile solids (organic) fraction of the settling material followed a seasonal pattern which peaked in the early fall. In terms of organic content, no clear-cut differences were evident from the limited coring in the two bays.

7. The quantity of nutrients (carbon, nitrogen, phosphorus) reaching Fahka Union Bay via Fahka Union Canal was more than five-fold the quantity passing Janes Scenic Drive and potentially entering Fahkahatchee Bay. However, due to short-circuiting of nutrients entering Fahka Union Bay, concentrations of nutrients in Fahkahatchee Bay were generally greater than those in Fahka Union Bay.

Large amounts of organic carbon enter Fahkahatchee Bay from the salt marshes and mangrove forests via tidal creeks. The carbon material is reduced in the bay to more soluble forms. In mid-October, of the daily net quantity of carbon released via Fahkahatchee Bay to the Gulf of Mexico, at least two-thirds of this quantity originated from the mainland salt marshes and mangrove forests.

On ebb tides, Fahkahatchee Bay received considerably less organic carbon per unit area than did Fahka Union Bay. The latter bay received large freshwater flows via the Fahka Union Canal from a network of drainage canals extending as far north as Corkscrew Swamp Sanctuary. However, because Fahka Union Canal channelizes its flow through the bay, a major portion of its load is "short circuited" to the Gulf of Mexico.

8. Canals receiving runoff from developed areas showed a buildup of metals in bottom sediments.

9. Concentration of metals in the sediments of Fahka Union Bay were on the order of two to three times greater than those in Fahkahatchee Bay. Freshwater discharge from the Fahka Union Canal and the lack of the potential filtering mechanism of mangrove forests appear to be the cause of this disparity. The long term effect of this buildup of metals is not known at this time.

10. No major difference in toxic metal concentrations was found in waters from either canals or natural areas.

11. Low concentrations of pesticides were detected in sediments and biological samples such as sport and commercially important fishes and shellfish. This shows that pesticides are present in the aquatic environment of south Florida.

12. Normal overland sheet flow of freshwater along a broad front infuses minerals and nutrients into coastal salt marshes and mangrove communities. Drainage canals short-circuit sheet flow and divert waterborne minerals and nutrients directly to estuarine waters where they are rapidly incorporated into sediment and are exported into the Gulf of Mexico. Mineral losses from short-circuiting processes result in reduced primary productivity of salt marshes and mangrove communities and thereby lessen the export to the estuary of detrital materials that form the basic food source for fishery resources.

13. Mangrove ecosystems represent a key factor in the natural economy of south Florida's estuarine ecosystems. They provide a habitat and substrate for many fish and aquatic organisms and also provide detritus through leaf fall throughout the year.

14. The community trend in mangrove metabolism is a function of a synergistic action between nutrient availability and tidal flushing.

15. Fahka Union Bay supported a benthic plant community comprised mainly of green filamentous and red macroalgae, whereas Fahkahatchee Bay maintained a

benthic plant community which consisted primarily of marine grasses. These grasses provided extensive habitat for numerous species of invertebrates and juvenile and adult forage and sport fishes. There is no apparent reason to suspect that Fahka Union Bay ever supported an extensive community of marine grasses.

16. Gross primary productivity of benthic plant communities in Fahka Union and Fahkahatchee Bays represented a small fraction of that maintained by the contiguous mangrove ecosystems.

17. Drainage works effected a reduction in primary productivity in cypress forests and wet prairie ecosystems. Reductions in productivity were directly proportional to diminished freshwater availability. Cypress forests in undrained regions maintained primary productivity rates nearly ten times that of drained areas.

18. The draining of wet prairies that are normally inundated during the wet season induced a series of undesirable side effects:

- Periphytic algal growths, which form the food base for much of the population increases of small forage fishes, were completely suppressed.
- The prairies became unavailable as habitats for populations of small fishes because of the lack of standing water.
- The population levels of larger animals dependent on these resources for their food supply necessarily declined, especially the wading bird communities.

19. Drainage of the cypress forest initiates a canopy thinning process which leads to greater light penetration to the forest floor. The consequences of a dryer understory leads to changes in microclimatic conditions unfavorable for litter decay. Thus, litter accumulation is accelerated and leads to increased fuel sources for destructive wildfires.

20. Dependence of the plant communities on direct rainfall alone for water supply induces at the very least a 40 percent drop in net primary production, which represents an equivalent drop in magnitude of the carrying capacity of the ecosystem for wildlife.

21. Responses of the biological communities of the area to seemingly mild drying shifts in hydrologic conditions are surprisingly large. Net production is markedly depressed, posing a major threat to dependent wildlife populations.

22. The smallest standing crop of fishes per unit area of water in Fahkahatchee Strand occurred during the wet season (summer and fall) when opportunities for dispersal were greatest. The concentration of fishes per unit area steadily increased as the surface waters receded during the dry months (winter and spring).

23. Predominant freshwater fishes in the Strand belonged to the following families: Livebearers (Poeciliidae), killifishes (Cyprinodontidae), sunfishes (Centrarchidae), and catfishes (Ictaluridae). Ecologically, these fishes function as intermediate links in the food chain between primary producers and numerous fish-eating predators, such as wading birds, alligators, turtles,

snakes, and other animals.

24. Standing crop of fishes in the Tamiami and Fahkahatchee borrow canals greatly exceeded the standing crop associated with GAC drainage canals.

25. A greater abundance and diversity of fishes inhabited Fahkahatchee Bay, an essentially undisturbed estuary, than in Fahka Union Bay, a man-influenced environment. Major dissimilarities between the bays existed in the composition of benthic fishes and the bottom plant communities. Numerous benthic fishes, such as pinfish and silver perch, were associated with the stands of grass beds in Fahkahatchee Bay, whereas these grasses and their fish inhabitants were sparce in the disturbed bay.

26. Tidal streams in the upper reaches of the estuary were identified for the first time as the major nursery grounds for juvenile snook, Centropomus undecimalis, in the Ten Thousand Islands.

27. Random land development patterns have led to the use of small wastewater treatment facilities. An end result of this continuing trend is that many small plants are serving areas which could presently be served by a central plant. Nearly 90 percent of the wastewater treatment plants listed were of a design capacity of less than 50,000 gpd.

28. A majority of the waste treatment facilities are "package plants" designed to provide secondary treatment. However, the efficiency of these plants is questionable due to a severe lack of qualified operators.

RECOMMENDATIONS

GENERAL

1. Recognizing the potentially severe seasonal water shortages of this region and the consequence of a unique local climate and geomorphology, regional watershed management plans and applicability to south Florida of the law of "riparian rights" are essential, especially to the interaction of competing agircultural, residential, recreational, and biologically-related water use patterns. Without management plans and riparian principles, a major disruption in the present diverse, stable (long-term), and productive natural ecosystems will occur.

SURFACE WATERS

2. The philosophy of direct surface water removal should be replaced by one of surface water redistribution. Canal drainage systems and borrow canals that currently waste excessive quantities of surface waters by open channel connections to the Gulf of Mexico should be eliminated. Control structures should be installed in all present north-south canal works in southern Collier County. These structures should direct waters from GAC, Barron River (S.R. 29), and any other north-south canals into the Alligator Alley borrow canal. The latter could serve as a distributor canal, reinjecting surface flow on a broad front into the Fahkahatchee Strand and other areas of the Big Cypress. The Tamiami Trail (U.S. 41) canal could serve a similar function in restoring sheet flow to the mainland salt marshes and mangrove forests.

GROUND WATERS

3. Present borrow and canal drainage systems should be modified by adding adjustable weirs and dikes or other water level control structures designed to minimize the hydraulic gradient between canal water and groundwater levels.

4. Developers of water supply well fields should be more acutely conscious of the implications of the Ghyben-Herzberg relationship*, and the interaction of man's patterns of water supply utilization with regional hydrologic dynamics. Water management districts should prohibit the over-utilization of groundwater resources by private developers at the expense of the county as a whole.

WATER BUDGET

5. All land development plans need to include studies of management alternatives and recommended actions to control the effects of development on both the local and regional hydrologic budgets. These studies must include estimates of impacts of developments on both downstream and upstream water users, and must take into account both long-term and short-term variations in climatic activity cycles. Water

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*Because of a lower specific gravity, freshwater floats on top of saltwater. The depth to the saltwater is related to the height of the freshwater above mean sea level. Assuming a specific gravity of 1.025 for seawater, then for each foot of freshwater which occurs above sea level, 40 feet of freshwater extends below mean sea level. Therefore, a lowering of the freshwater table one foot would increase the level of saline water by 40 feet.

budgets based on long-term mean conditions do not adequately portray potential impact on systems which require extreme hydroperiod variations.

NATURAL ECOSYSTEMS (ZONING)

6. Slough and strand ecosystems are uniquely valuable as water and wildlife reservoirs, and should have a special zoning category designed for their preservation, including a substantial buffer fringe of wet prairie or pineland.

7. Mangrove forests, especially those located in mainland zones receiving overland freshwaters, are of key importance to overall estuarine productivity, including commercial and sports fisheries. Special zoning measures should be utilized to minimize destructive interference with these resources.

8. Benthic marine grass communities must be recognized as uniquely valuable habitats for the production of numerous species of invertebrates and fishes. Safeguards for protection of the natural ecosystem should be inherent in all zoning in coastal and upland regions.

MONITORING

9. The effect of fluctuations (natural and man-induced) in the hydrologic cycle on water quality should be monitored regularly. Monitoring data should then be used in development of programs of water quality management, integrating both technological and natural ecosystem components as a composite system of water quality control.

CONTROL OF TOXIC INPUTS

10. Introduction of pesticides, herbicides, heavy metals, and enteric bacteria into south Florida waters poses a major threat to all water conservation and wildlife protection programs. Careful monitoring of toxic elements in water, sediments, and biota, coupled with regulations to prevent point source discharge of toxic materials, is of the utmost importance. Also, programs of need-oriented agricultural chemical application, for example those currently under development at the Immokalee Experiment Station, should receive the widest possible support and implementation.

11. Accelerated transport (as in canals) of toxic heavy metals to estuarine ecosystems must be carefully controlled. Sheet flow across mangrove ecosystems appears to provide one efficient downstream filtering mechanism for heavy metal removal, but long-term effects within the mangrove zone are virtually unknown.

ECONOMICS

12. Bond issues, cost sharing plans, and aid from other governmental organizations should be used to equalize economic impact of conservation measures on individual landowners.

IMPLEMENTATION

13. As with so many noble efforts gathering dust on a shelf, the lack of mechanisms to implement the above recommendations is a weakness in south Florida at present. Some state interest has been directed toward implementation mechanisms, i.e. institutional programs, but more needs to be done. Federal legislation to protect unique parts of south Florida also needs to be accelerated because the area is growing rapidly and it may soon be too late.

III - DISCUSSION

This chapter is devoted to development of an analysis of the Fahkahatchee regional ecosystem, and a discussion of the consequences of cultural environmental perturbations to that ecosystem. An exposition of the methods of ecosystem analysis utilized in the study can be found in Odum (1971). A brief discussion of some of the relevant concepts and the circuit language used in model development is given in Appendix A. In this chapter, we first present a set of overall ecosystem models, and describe our general hypotheses on system functioning that are exemplified by the models. Next, some of our overall study results are discussed using smaller process subunits of the models as a device to place each individual study within its larger context. In addition, we evaluate from the model concepts and accumulated data some longer term patterns and trends for the Fahkahatchee ecosystem, emphasizing the consequences of artificial drainage to ecosystem structure and dynamics.

UPLAND ECOSYSTEM

An ecosystem model of the upland terrestrial systems of the study area is presented in Figure III-1. Sunlight and rainfall are shown as the basic source

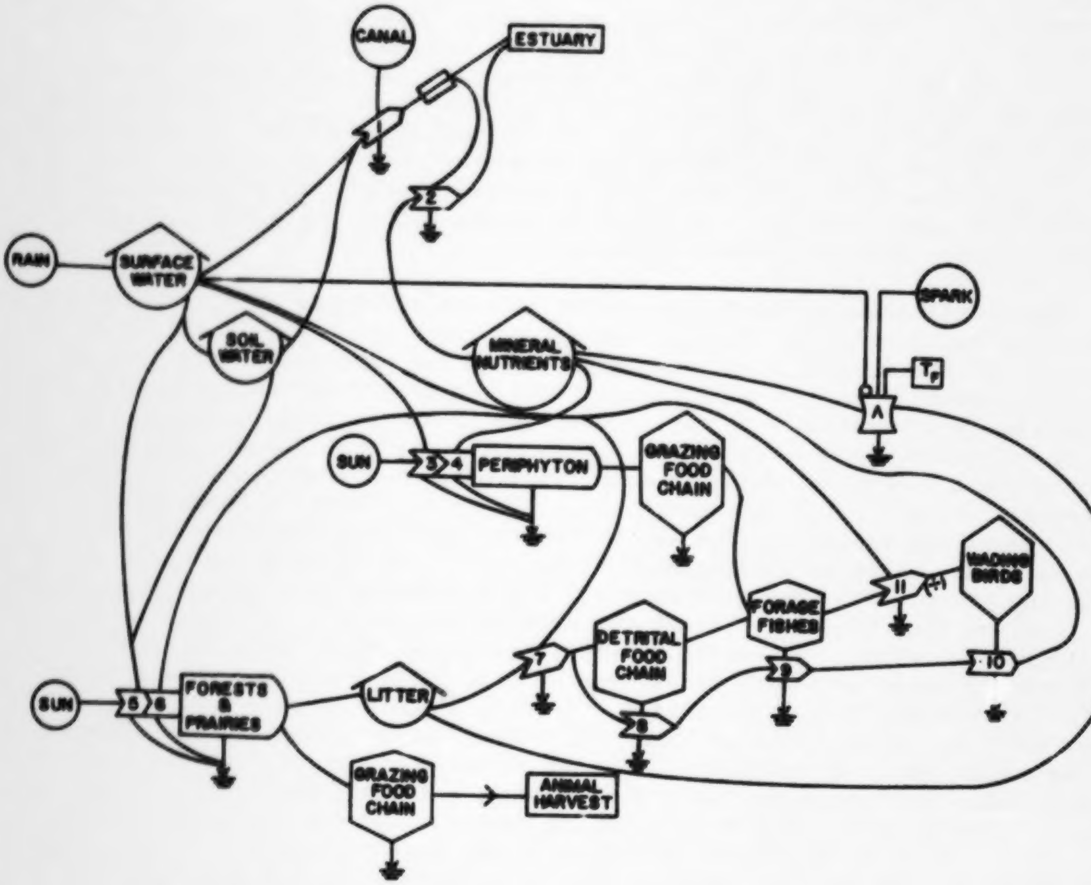
CANAL
ESTUARY
1
2
RAIN
SURFACE WATER
SOIL WATER
SPARK
MINERAL NUTRIENTS
T_F
A
SUN
3
4
PERIPHYTON
GRAZING FOOD CHAIN
WADING BIRDS
11
(-)
FORAGE FISHES
DETRITAL FOOD CHAIN
7
8
9
10
SUN
5
6
FORESTS & PRAIRIES
LITTER
GRAZING FOOD CHAIN
ANIMAL HARVEST

Figure III-1. Upland ecosystem model.

terms of the model. In many parts of the study area overland flow contributed surface water to particular sites, but during the study year overland flow into the study area as a whole was nearly negligible. Canals are shown as a driving force diverting surface water and ground (soil) water to the estuary. The work gate (Block 1) for canal action is taken here to have an intrinsic conductivity, even in the absence of canals, that represents overland export of water across U. S. 41 from the upland to the estuarine salt marshes and mangrove forests. An export of mineral nutrients from the upland to the estuary takes place in tandem with the flow of water (Block 2). The export of minerals is a function of the volume of water flowing to the estuary and the concentrations of mineral nutrients in the flowing waters.

Periphyton growth, a feature especially of the wet prairies in the study area, is utilized by a grazing food chain that terminates in the production of small forage fishes and a carnivore food chain. Periphyton populations require standing surface water in the prairies in order to develop (Block 3), and their productivity may be partially governed by the availability of mineral nutrients (Block 4) for incorporation into photosynthate derived from sunlight. The forest and prairie ecosystems draw dissolved nutrients and water for evapotranspiration primarily from soil water, but the effect of evapotranspiration water loss can be observed in surface water levels as well (Blocks 5 and 6). These communities support a grazing food chain that results, inter alia, in an annual deer harvest by human hunters. Litter produced by forests and prairies fuels a detrital food chain that, like the periphyton sequence, results in the production of small forage fishes. The hydroperiod (surface water) controls the rate of flow of litter into the food chain (Block 7). As is the case with all the conductivity work gates in this set of models, there is a non-zero baseline transfer rate that holds during the absence of standing water in the system. The hydroperiod acts to accelerate this transfer (Block 7) by maintaining a high moisture content of the litter and by making litter available to aquatic and semi-aquatic macro-decomposer organisms.

Remineralization of dead plant material is accelerated by the activities of the detrital food chain, forage fishes, and birds (Blocks 8, 9 and 10). In the course of its metabolic activity each population accelerates the flow of dead plant material back to mineral nutrients via decomposition process, which are then newly re-available to the photosynthetic energy production process. Once again, these blocks, e.g. Block 10, do not imply that the process ceases in the absence of wading birds, it merely suggests that remineralization may be slowed if bird populations are absent. The role of fire is shown by the switch symbol controlling a flow to the mineral pool from the stock of dead plant material. Several conditions must be met for this switch to be in a conducting state. The condition that all input elements must be simultaneously true to allow flow to occur through the gate is indicated by the logic symbol "Λ" (logic AND) within the switch. First, the stock of litter must be above the threshold value necessary to propagate fire. This condition is shown as the fuel threshold "Tf" on the switch. Second, a spark must be provided, either by a lightning strike or from some human source. Finally, the material must be sufficiently dry to burn. This is shown by a control line from the surface water pool entering the switch through a logical NOT symbol (small circle). This simply means that litter in contact with surface water will not burn. The role of fire could be expanded in the model to reflect, for example, the burnoff of live prairie grasses, along with ground litter, and their regrowth from storage reserves in the root system. Prairie fires that only burn dead plant mass that is still standing upright (and the green shoots), in which fires may occur when there is some standing water in the prairies, could also be shown. However, the simplified portrayal of Figure III-1 is adequate to our purpose, in that it shows the role of fire in a general way and indicates some factors important in controlling the frequency of fire in the ecosystem.

Finally, the work gate (Block 11) that shows a controlling function of surface water on the availability of the stock of forage fishes to wading birds; represents concentration of the fishes in pools and depressions as water levels fall. It differs from the other blocks of this figure in that fish availability increases as water level decreases. This feature is suggested by the division (÷) sign placed next to the gate.

ESTUARINE SYSTEMS

The model of Figure III-2 is divided into three major blocks of land area. On the left, the upland ecosystems are shown simply as a source of fresh water and dissolved nutrients flowing to the estuary as in Figure III-1. The bottom central portion of the figure represents mainland mangrove forests and salt marshes, and the upper right-hand section of the figure shows the estuarine bay

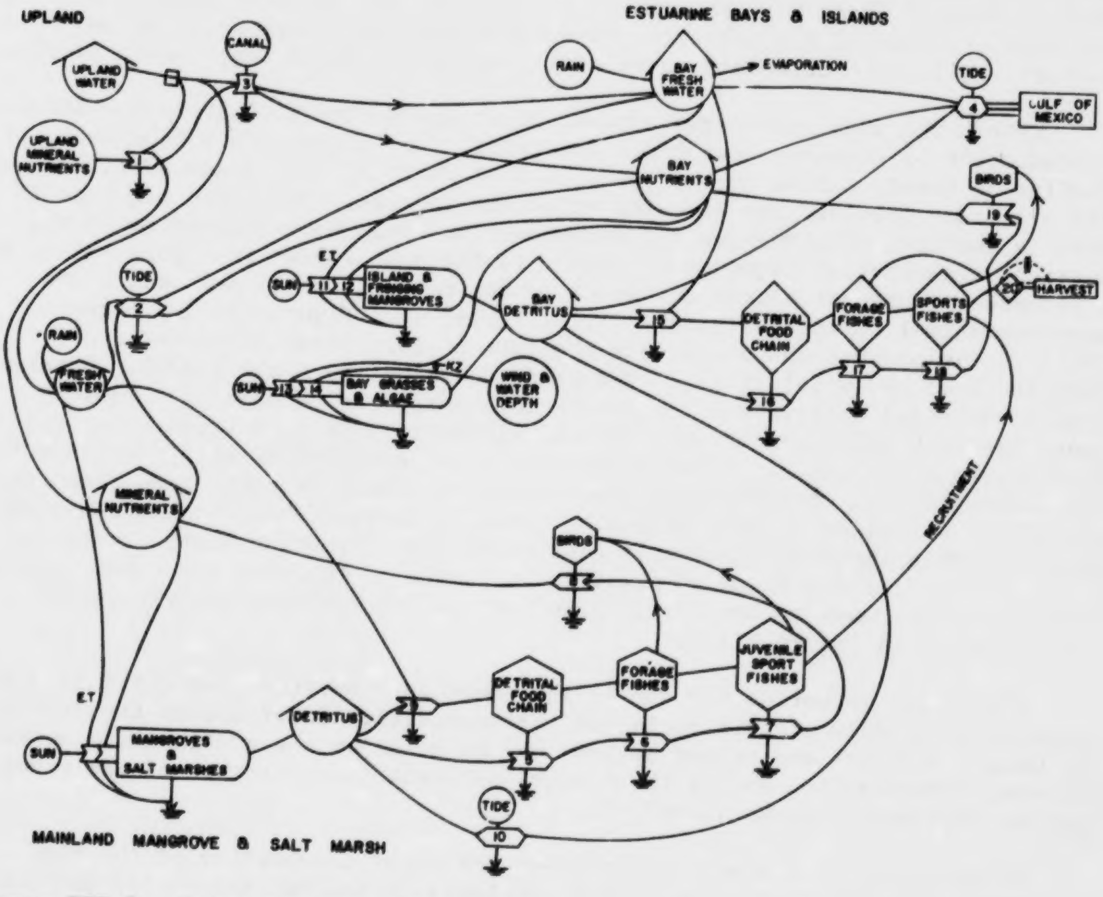
UPLAND
ESTUARINE BAYS & ISLANDS
UPLAND WATER
CANAL
3
RAIN
BAY FRESH WATER
EVAPORATION
TIDE
4
GULF OF MEXICO
UPLAND MINERAL NUTRIENTS
1
BAY NUTRIENTS
BIRDS
19
E.T.
TIDE
SUN
11
12
ISLAND & FRINGING MANGROVES
BAY DETRITUS
15
DETRITAL FOOD CHAIN
FORAGE FISHES
SPORTS FISHES
20
HARVEST
2
RAIN
FRESH WATER
K2
SUN
13
14
BAY GRASSES & ALGAE
WIND & WATER DEPTH
17
18
16
MINERAL NUTRIENTS
RECRUITMENT
BIRDS
E.T.
JUVENILE SPORT FISHES
DETRITAL FOOD CHAIN
FORAGE FISHES
DETRITUS
SUN
MANGROVES & SALT MARSHES
5
6
7
TIDE
10
MAINLAND MANGROVE & SALT MARSH

Figure III-2. Estuarine ecosystem model.

ecosystem and its fringing mangroves and island mangrove forests. The Gulf of Mexico appears on the far right of the model as the ultimate sink for fresh water, nutrients, and detritus in the estuary.

As in Figure III-1, the flow of water from the uplands entrains a flow of nutrients in proportion to the concentrations of nutrients in the water (Figure III-2, process Block 1). Under sheet flow conditions, these waters and minerals enter the mainland mangrove and salt marsh zone, where they act as source terms for evapotranspiration and as a mineral nutrient supply for the photosynthetic activities of the plant communities. The "fresh water" storages in this model are intended in the sense of a dilution of sea water, that is, if pure sea water is present in the marsh it would be shown as zero fresh water, and conversely.

Marsh fresh water and nutrients are exchanged with the estuarine bay by the action of the tides (Block 2). The net exchange, as shown by the use of a two-way gate (Figure i - Appendix A), will depend on the relative salinities and mineral concentrations between the two water bodies and the volume of tidal exchange. Under drained conditions, the canal network acts as a switch (Block 3) that bypasses the mainland mangrove and salt marsh ecosystems and delivers fresh water and nutrients directly to the bays. In this case, delivery of upland fresh water and nutrients to mainland systems will only occur by tidal exchange from the bays, and much of it may be lost by tidal exchange with the Gulf of Mexico (Block 4). The extent of any loss of this kind would depend on the flushing rate of the estuarine bays. The mainland zones would become proportionally more dependent on rainfall inputs for their fresh water supply.

Within the mainland mangrove zone, plant production ultimately results in a production of detritus that fuels a detrital food chain. This food chain is similar in broad outline to the detrital food chain of the upland zone, although the organisms involved may be quite different species. The basic sequence is again a function of scavenger and decomposer action. An acceleration of the nutrient regeneration sequence is shown, in the same way as in Figure III-1, by a sequence of process blocks subtended to the populations of salt marsh and mangrove animal residents (Blocks 5, 6, 7, and 8 of Figure III-2). Fresh water in the marshes again controls the rate of incorporation of detritus into the food chain (Block 9) in the sense described by Heald (1971). Breakdown of detrital materials was shown by this author to proceed most rapidly under brackish water conditions, and was slowed in both pure fresh water and full strength sea water. Detrital materials not consumed directly on the marsh are exchanged with estuarine bay systems via the tidal exchange gate shown as Block 10. Juveniles of many species ("Juvenile Sport Fishes" population) may develop within these mainland salt ecosystems where brackish water conditions protect them from predation by piscivorous adults of the same and other species. Eventually they move to the bays, shown here as the transfer pathway marked "recruitment" in Figure III-2.

Within the estuarine bay and island mangrove ecosystems two distinct plant communities produce organic fuels for the ecosystem. Solar energy fixation by the mangrove fringe and island systems may be gated by the availability of water for evapotranspiration and by the mineral nutrient concentration of bay waters washing this zone (Blocks 11 and 12).

Productivity of the marine "grasses" and algal communities of the bays themselves is controlled by available nutrients in the bay (Block 13) and the turbidity of the bay waters (Block 14). The extinction coefficient of the water governs the transmission of light to bay bottom communities by the well known exponential relationship

$$I = I_o e^{-kz}, \qquad \text{(Eq. III-1)}$$

where if I_o is taken as visible light input at the water surface, z as the depth of the water column, and k as the extinction coefficient; then I is the light reaching the bottom community. Turbid waters are produced within these shallow bays by the action of wind induced stirring of loose sediments from the bottom into the water column. The transfer of momentum from moving air to the sediment surface is less efficient as the depth of the water body that must first be set in motion increases. Thus, the turbidity of a given bay is an independent function of the average depth of the bay, assuming the inputs of stirring energy from wind to any two bays is the same. In this sense, the light intensity reaching bay-bottom communities is a "double" function of the depth of the bay. First, depth determines the efficiency of the wind in producing turbid water. Second, light transmission to the bottom is then a function of turbidity (extinction coefficient) and the path length of incident light energy given by the depth of the bay as in Beer's Law (Equation III-1 above). This situation is summarized by the source term to Block 14 marked "wind and water depth", and the pathway notation "e^{-kz}".

Both the bay bottom plant communities and the associated mangrove communities contribute to the detritus pool in the bays. Paralleling the situation in the upland mangrove zone, energy flow into the detrital food chain may be salinity dependent (control line from "Bay Fresh Water" at Block 15). The remineralization sequence proceeds as before through the decomposition sequence of Blocks 16, 17, 18, and 19, resulting in release of minerals bound in detritus for re-incorporation into new plant tissue. Once again, we caution the reader that each block represents an acceleration factor in the remineralization sequence, so loss of a block does not halt, but does slow, the total process.

The bird populations that appear at the top of both the bay and mainland food chains are in many respects the same population. They have been separated in this figure mostly for the sake of clarity in the figure. These bird populations may act to transfer minerals from bays back to terrestrial mainland communities. This factor could be of some importance to counter-current inter-system mineral transfers. A possible magnitude for this process is suggested by the observation that bird rookeries can produce sufficient quantities of phosphorus in their excreta to result in phosphate rock concretions in nearby waters (Lund, 1958). However, as we were not able to explicitly assess this factor in our field investigations, we have omitted it from the present model.

Finally, the sports fish populations of the bay are harvested by an extensive guide and tourist industry within the region. This industry is portrayed by the economic transactor module at Block 20. The economic importance and estuarine dependence of the penaeid shrimp populations and commercial fisheries are not shown for two reasons. One, as with the birds, we did not explicitly assess the commercial fisheries in our field work. Secondly, the sports fishery will, we hope, serve as an adequate descriptor of mans dependence on estuarine ecosystems for part of his economic well being.

Several major questions are immediately suggested by these models. For example, in the model of Figure III-1, to what extent do canals remove surface and soil water? How does this modify plant productivity, litter fall, and litter remineralization rates? What is the effect on the food chains that ultimately support south Florida's populations of spectacular wading birds?

Within the estuarine system, do canal inputs substantially modify salinity and dissolved nutrient regimes? To what extent are minerals merely exported to the Gulf from these bays, and to what extent are they infused into mainland marsh and mangrove ecosystems by tidal exchange? What are the relative magnitudes of detrital inputs to bay systems from the resident plant populations and from the mangrove communities?

In the next section of the report we summarize our findings directed at providing magnitudes for some of the flow patterns shown in the models, as steps toward answering the above questions.

ANALYTICAL RESULTS

Rainfall and sunlight act as the major forcing functions or input source terms of Figure III-1. The U. S. Weather Bureau has maintained a station at Everglades City in our study area for about the last 40 years. The month-by-month long term average rainfall and temperature data from this station can be seen in Figure III-3a, presented according to the scheme devised by Koppen (1931) and used by Walter and Lieth in their worldwide climate atlas (1960-1967). The monthly mean patterns for the Fahkahatchee Strand in 1972 are given in Figure III-3b. These means are based on a network of four recording rain gages plus two complete weather stations operated in the Strand during the study year, plus records from Everglades City and a State Forest Service installation at Copeland (Figure VI-1). Scales for both diagrams, for precipitation, temperature, and time, are shown in Figure III-3b. This presentation scheme portrays the general interaction of rainfall and temperature as it affects moisture availability to plant communities. In those months in which the precipitation curve dips below the temperature curve, the stippled area serves as a measure of the intensity and duration of moisture stress to the plant community. The hatched areas cover humid periods, and precipitation values greater than 110 mm are printed in a scale of 1:10 against temperature and marked in black. Rainfall during the study year was slightly above the long term mean (1,440 mm vs 1,371 mm), with notable upward departures in February, March, and November, and an unusually dry October. Another noticeable departure from the long-term can be seen in the unusually high mean daily temperatures that prevailed in early 1972.

Although these graphs indicate in a general way the climatic regime of the Strand, the detailed relationship between water import in rainfall and export via evaporative processes depends on sun, wind, and the saturation deficit of the air. This relationship is shown in Figure III-4. The sun provides the basic driving force to the process, vaporizing water at a conversion proportion of about 590 calories per gram of water (Block 1). The evaporation process is conditioned by the action of wind in removing water vapor, and by the relative humidity or saturation deficit of the air mass (Block 2). Saturation deficit expresses the ability of the air mass to absorb water vapor from free water surfaces, or from the plant water release process.

Insolation during the study year is given in Figure III-5. This curve represents monthly mean daily solar energy input as measured by a pyrheliometer at one of our weather stations. The high values for early 1972 appear to account for the unusually high temperatures seen in Figure III-3b. Mean windspeeds and saturation deficit are shown in Figure III-6. The windspeed data were provided by B. J. Yokel and the Rookery Bay Project. Saturation deficit in millibars is the average for our upland and lowland weather stations. Daily air mass characteristics were calculated using noon temperatures and relative humidity from the two stations. We used a modification of Penman's method of calculating potential evapotranspiration from these data (further discussed in Chapter VI), and compared this result to the average evaporation from open water surfaces. Free water evaporation was measured by two evaporation pans equipped with recorders, one at each weather station. In Figure III-7, the solid line is theoretically calculated evaporation and the circles are mean monthly evaporation as an average of the two pans. Least squares regression of these two data sets yielded a coefficient of correlation (r) of 0.94 and the equation (in mm H_2O)

$$\text{Pan Evap.} = 1.03\ (\text{Potential E.-T.}) - 11.24, \text{ with } P<0.001.$$

Pan evaporation and the potential water loss calculated from climatological parameters are thus in reasonably good agreement. This information could be used to estimate evaporative losses from estuarine bays, canals, ponds, and other open water surfaces in the study area. In the presence of extensive vegetation cover, however, this pattern can be substantially modified.

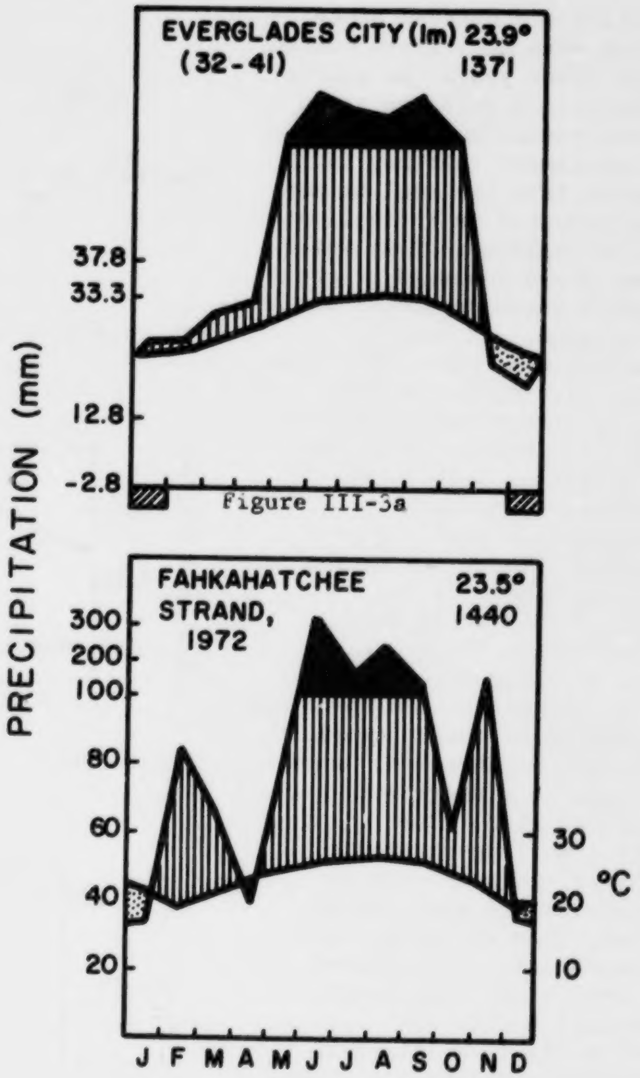

Figure III-3a

Figure III-3b.

Climatic diagrams. 3a., long term average. 3b., for 1972.

Continuous recordings from ground water observation wells can be used to estimate actual evapotranspirative water export. Detailed results for the study area are supplied in Chapter VI, we will outline only the logic of the calculation and the results in this chapter. Figure III-8 is a schematic representation of the evapotranspiration process set in the overall hydrologic dynamics of these swamp ecosystems. Overland surface water inputs to the strand are omitted since they were negligible during the study year. In general, rainfall within the study area enters a surface water compartment that may infiltrate into the soil or may be exported in surface water flow patterns. Soil water may drain downward to the water table as ground water recharge, and then be exported as subsurface flow. The driving forces for evapotranspiration exports are sun energy, wind, and saturation deficit as already discussed in connection with Figure III-4. Water use by the plant community can appear as losses from any of the three water storage compartments, and the sum of these water flows represents total actual evapotranspiration. Each requires a separate calculation. Diel changes in the slope of ground water recession curves provide the basic datum, and, when the water table surface is above ground level yield evapotranspiration discharge directly in millimeters of water (Block 1). When the water table is below ground level, apparent evapotranspiration must be corrected by the proportion of the soil volume that is gravity drainable water (Block 3) ("specific yield", Sy). We estimated Sy = 0.15 for the soils around our wells based on coupled major rainfall and ground water rise observations (Chapter VI). Finally, the soil layer between the water table and the ground surface retains much water (the "field capacity of the soil") that is available for plant transpiration (Block 2). This term must be measured somewhat indirectly. To obtain a maximum

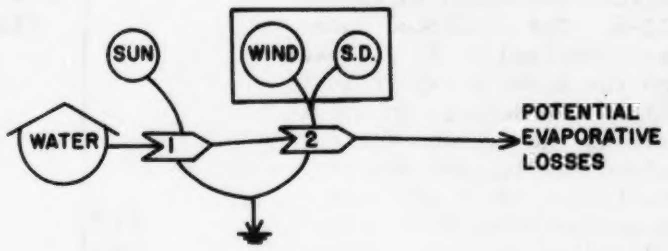

Figure III-4. Model of evaporation process.

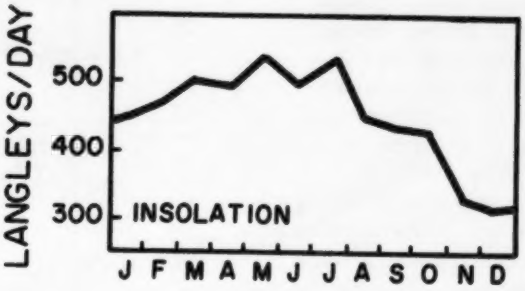

Figure III-5. Mean daily insolation, 1972.

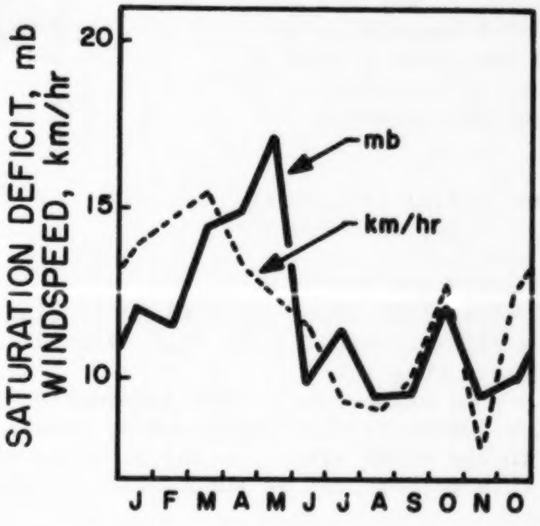

Figure III-6. Windspeed and saturation deficit.

estimate of this factor, we assumed that infiltration of surface water would be perfect when the water table was below the surface, i.e., that local surface runoff would be negligible. If the soil water compartment has been drawn below field capacity at the time of a given rainfall input, this deficit must be made up before much water can appear as a ground water table rise. Therefore, when the water table is below ground, soil water evapotranspiration can be no more than the difference between rainfall input and the observed ground water rise as a result of that rainfall, corrected by the specific yield. That is,

E.-T. (Field capacity) = rain - Sy (water table rise) (Eq. III-2)

when the analysis is restricted to periods when the water table is below the ground surface and the water table rise is directly attributable to paired rainfall records.

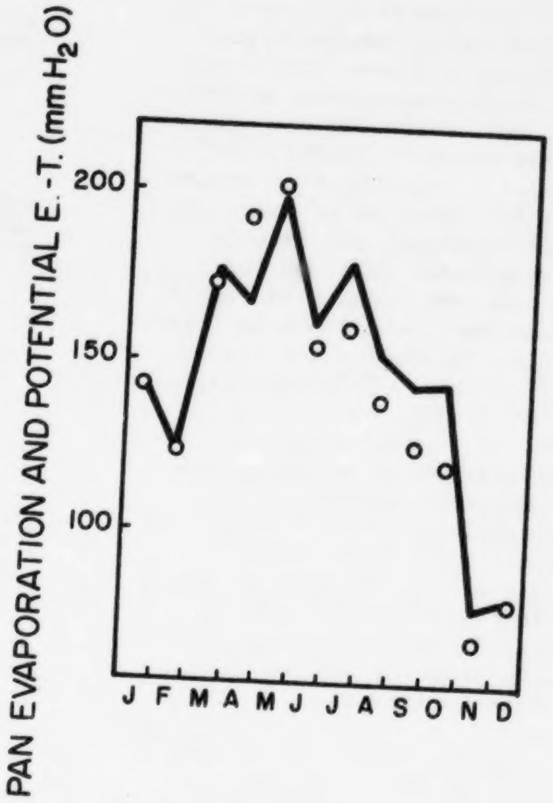

Figure III-7. Pan evaporation and potential evaporation, 1972.

The resulting curve for actual evapotranspiration (mean of four wells) appears in Figure III-9. The peaks in March, June, and October may represent periods when rainfall restored soil field capacity that had been depleted in previous periods of water scarcity, rather than true evapotranspiration peaks. The total evapotranspiration (1,100 mm) compares favorably with theoretical totals accumulated using methods proposed by Thornthwaite (1,179 mm) and Stewart (1,117 mm). This 1,100 mm of actual evapotranspiration represents 76 percent of total rainfall (1,440 mm). With this information, coupled with the data of Chapter VII (Hydrology), we can attempt to construct a complete water budget for the Strand during 1972 (Table III-1).

The total upland area of the Fahkahatchee study site was 28,961.2 ha. Using this figure, we convert mm of water in rainfall and evapotranspiration to cubic meters of water in the watershed. Subsurface export is the total ground water flow crossing U. S. 41 from the upland study zone, and the overland flow source term is a maximum estimator of water that entered the Strand across Alligator Alley (17 percent of flow crossing Janes Scenic Drive). To arrive at total surface water export from the Strand, 33 percent was added to the surface flow crossing Janes Scenic Drive to account for flow increments in the lower third of the strand as flowing waters approach U. S. 41. Yearly canal increments/mile were calculated using the regression equation of Figure VII-25 and the monthly mean stage at EPA Well W-2, corrected for effects of construction (3.095×10^6 m^3/mile · yr). We then assume that the total of 22 miles of canal bordering the Strand (Barron River Canal on the east and GAC Properties canals on the west) would act in this fashion, producing the figure in the table. This assumption is, of course, badly flawed. Canal weirs and changes in head differences would reduce ground water removal below the tabulated value. However, surface water flow into the canals is not included in the estimate, and would tend to cancel decreases from the listed value or perhaps even produce an increase.

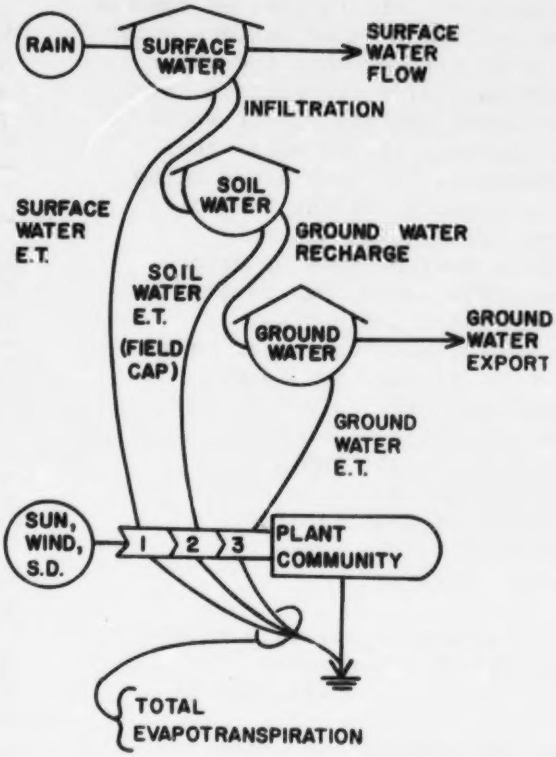
RAIN
SURFACE WATER
SURFACE WATER FLOW
INFILTRATION
SOIL WATER
SURFACE WATER E.T.
GROUND WATER RECHARGE
SOIL WATER E.T.
(FIELD CAP)
GROUND WATER
GROUND WATER EXPORT
GROUND WATER E.T.
SUN, WIND, S.D.
1
2
3
PLANT COMMUNITY
TOTAL EVAPOTRANSPIRATION

Figure III-8. Hydrologic model for upland strand.

In any case, the balance of sources and sinks is reasonably good (sinks account for 98 percent of source water), and is supported by the lack of any discernable major shift in overall water table levels between 1972 and 1973. In turn, the establishment of an overall balance without recourse to difference terms supports the approximate accuracy of the evapotranspiration figure.

In the south Florida ecosystem, although some major plant species (e.g., cypress trees) drop their leaves and remain dormant throughout the winter season, others (e.g., maples and willows) appear to be active throughout the year. To arrive at a yearly pattern of actual evapotranspiration then, correcting for the field capacity water use that only becomes manifest under rainy conditions, we modified pan evaporation (PE)rates to give the same total export as true evapotranspiration. Pan evaporation measures the driving forces

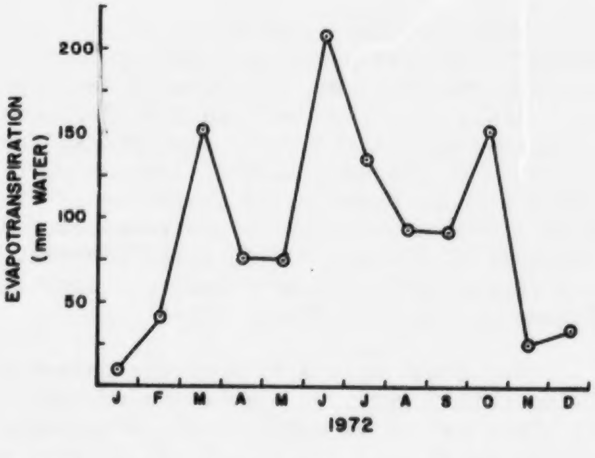

Figure III-9. Test well evapotranspiration.

Table III-1. Water budget for upland Strand, 1972.

Sources	$10^8\ m^3$	mm H_2O	Sinks	$10^8\ m^3$	mm H_2O
Rainfall	4.160	1,440	Evapotranspiration	3.160	1,100
Overland flow	.034	12	Subsurface export	.011	4
			Janes Drive surface flow	.201	69
			+ 1/3	.067	23
			Canal flow	.681	235
	4.194	1,452		4.120	1,431

available to this form of water export, and we adjust the total to give 1,100 mm export or 65.4 percent of total yearly pan evaporation (PE). This result is given in Figure III-10, along with the rainfall delivery rates for each month of the year. In this figure, the solid areas represent excess water that is available for ground water and field capacity recharge, the hatched areas show periods when plant community demand exceeds the monthly supply. The presentation in this figure is similar to that of the climate diagrams of Figure III-3, except the total in the present figure represents estimated actual evapotranspiration rather than a derived estimate based on temperature.

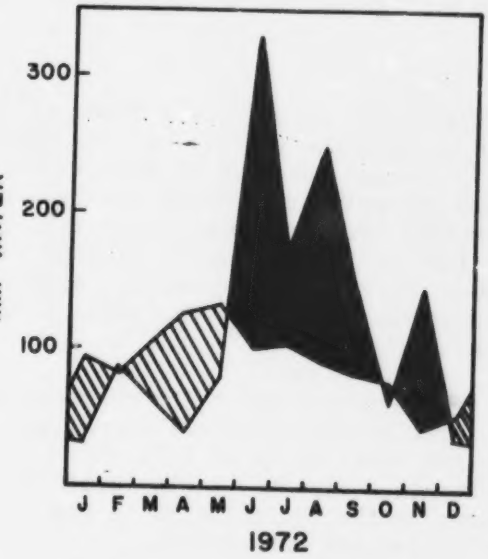

Figure III-10. Rainfall and actual evapotranspiration.

This figure can be compared to Figure III-11, which shows the seasonal pattern of the ground water table referred to ground surface elevation as a base line. The seasonal patterns in the wells generally agree with the relationship shown in Figure III-5. The early spring drawdown corresponds to the period of heavy net water export shown for the same period in Figure III-10. Recharge peaks (Figure III-11) in February, June, August, and November seem to correlate nicely with water availability peaks in those same months in Figure III-10. The discrepancy in magnitude correlation for February probably represents levels of plant activity below the mean of 65 percent of PE.

Figure III-11 also serves as a comparison of ground water dynamics between sites that were near canals and sites remote from canals. The upper

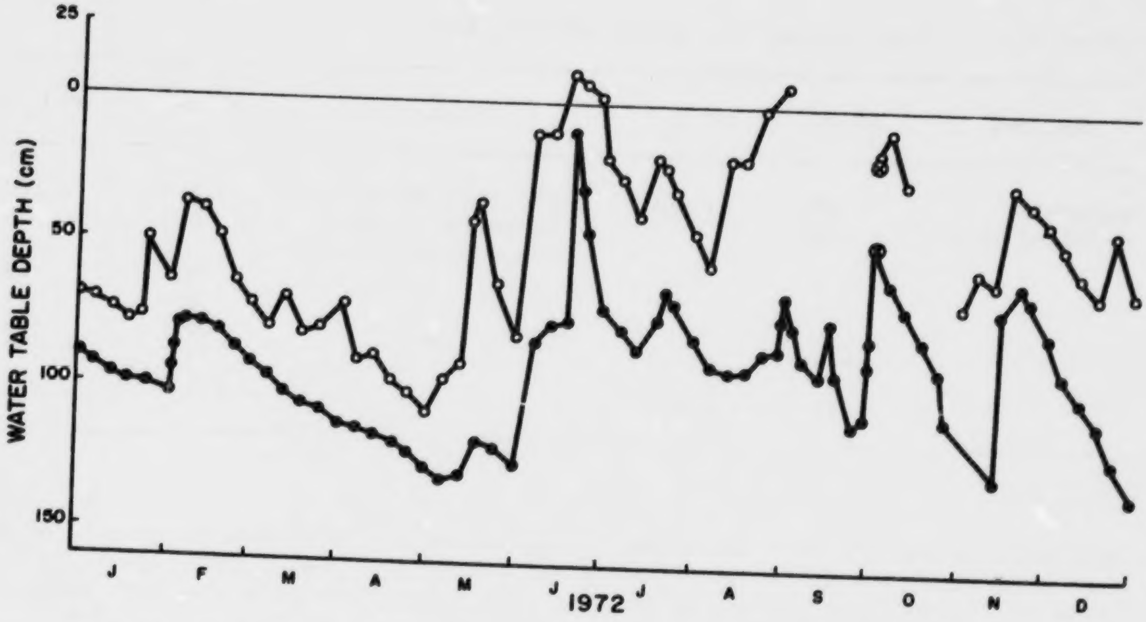

Figure III-11. Water table depths, test wells.

curve is the stage record from well W-5, a wet prairie area near Remuda Ranch, 1.8 km from the nearest canal. The lower curve represents the trace at well W-3, located some 0.3 km from a canal. The portions of this (W-3) record that were strongly affected by construction activities in the nearby canal have been omitted. Polar planimetry of this figure for the period up to the recorder failure in late August yielded an average difference between sites of 42 cm. Thus, the approximate average effect of drainage canals during the study year was to maintain the water table at a depth 42 cm below normal at sites near canals.

Our paired sites for observation of plant community metabolism were located at similar distances vis-à-vis canal locations. In early October we excavated to the water table at both sites to check the accuracy of these well records as indicators of water table levels at the metabolism sites. Our findings are shown as the encircled Xs in Figure III-11, and appear to at least partially validate this assumption.

The role of these hydrologic factors within the swamp forest ecosystem is shown in Figure III-12. The availability of water to the plant community controls the facility with which the system can convert sunlight to organic energy (Block 1). In this sense the canal-driven water export process (Block 2) competes with the plant community for water resources. Within the forest, the rate of litter-fall may be related to net productivity of the plant community. The forest floor litter is remineralized with an assist from a detrital food chain (Block 3). The overall dynamics of the remineralization process may be governed by moisture conditions in the forest (Block 4). Finally, minerals enter the plant transpiration stream and are incorporated into new protoplasm

(Block 5).

Annual net above-ground productivity increases in linear proportion to yearly actual evapotranspiration (AET). Figure III-13, redrawn from Rosenzweig (1968) and data of Odum (1970), sets forth this relationship for the broad range of terrestrial ecosystems. Arctic tundra, deserts, temperate forests, and tropical rain forests are all represented in this graph. One of our major objectives was to determine the extent to which this relationship holds true for the detailed operation of ecosystems within a given climatic zone, and the modifications that might be induced by artificial drainage.

Yearly net production is the sum of several factors. A large part of the total energy fixation in an ecosystem is utilized directly by the autotrophic community for maintenance activities. The remainder, net primary production, may appear as a net change in standing crop, as removals by grazing food chains, and as litter-fall or detritus production (Figure III-12). The effect of a 42 cm water table lowering on the net production of cypress strands is summarized in Table III-2 (details in Chapter XII).

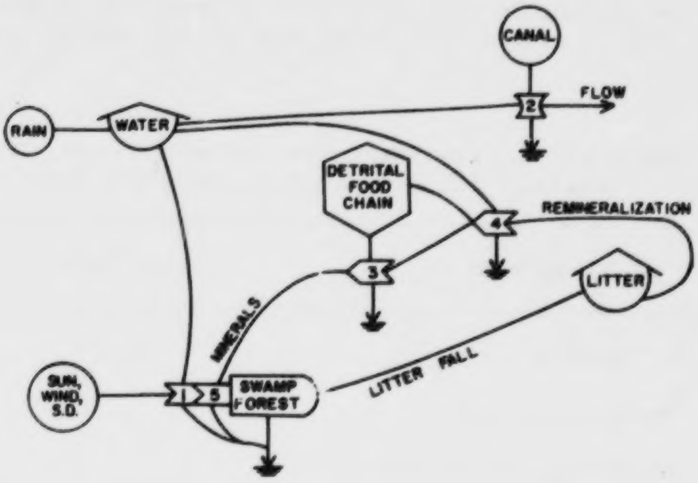

Figure III-12. Swamp forest dynamics.

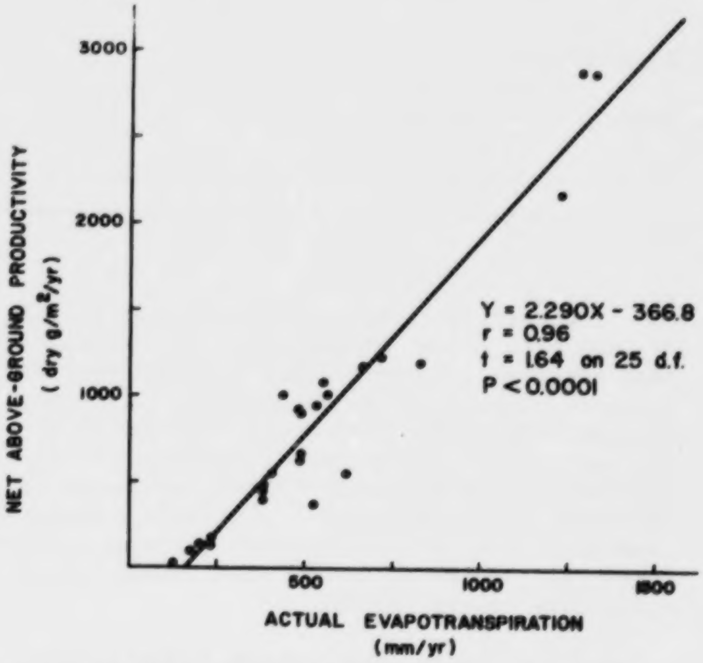

Figure III-13. Productivity and actual evapotranspiration, worldwide.

The biomass production is broken down in Table III-2 by woody plant species and herbaceous ground cover plants. All three components of net production show a decrease in cross-site comparisons. The herb layer shows an absolute decline in the drained site, suggesting that ultimate loss of this layer of the community may occur. The total biomass in the natural strand was twice that in the drained strand, but this factor fails to account for the difference in woody plant growth, as the undrained site shows a growth four times that on the drained site.

Table III-2. Cypress strand net production, 1972, for drained and undrained sites. (All values gm dry weight/m^2/year)

Component	Near Canal	Undisturbed
Litterfall	267.2	373.2
Woody Plant Growth	119.6	485.0
Understory Herbaceous Plants	-20.0	311.6
	366.8	1169.8
	Mean Standing Crops (Kg dry weight/m^2)	
Woody Plants	8.9	17.1
Herbs	1.2	1.9
Total	10.1	19.0

Interestingly, the relative litter-fall is 45 percent greater in the drained site, based on the ratio of leaf litter-fall to mean standing crop of leaf material (turnover rates of 0.713 vs 1.035). This suggests that the response of this system to moisture stress may involve a process of thinning in canopy density. This would reduce moisture loss by reducing the size of the available water-exporting surface. If this is the case, two consequences are immediately apparent. First, decreases in system leaf tissue will entrain decreases in productivity. That this decrease in fact takes place is obvious from the table. Second, canopy thinning permits more sunlight to reach the forest floor, drying accumulated litter debris and making the system more vulnerable to fire damage.

We have postulated a relationship between the cycling rate of mineral nutrients and moisture conditions in the forest (Figures III-11 and 12). This hypothesis is explicitly presented in the model of Figure III-14. Litter materials reaching the forest floor ("Duff", Q) have an energy content that fuels a detrital food chain. In the process of utilizing this energy for growth and reproduction, much of the original plant carbon is released as CO_2 gas. However, other materials, for example phosphorus and nitrogen, are retained within the system. This results in an increase in the relative ash content of the remaining litter, which can be expressed as an increase in mineral nutrient concentration (Block 1). The build-up of nutrient concentration during the soil formation process makes these materials more available for recycling (Block 2) to the plant community. The role of moisture in this system is shown at Block 3. Water accelerates the process by producing conditions favorable to small organisms (macro-decomposers) that break down the litter to fine particles. The fine particles are further acted on by bacteria and fungi that are also favored by moist conditions.

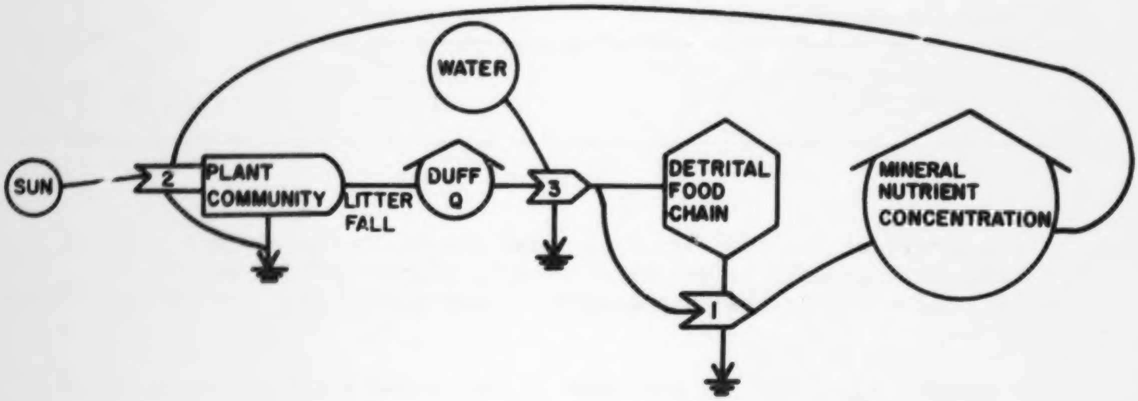

Figure III-14. Model of litter remineralization sequences.

The breakdown rate of a unit parcel of litter materials can be described by the equation

$$\frac{dQ}{dt} = -kQ \qquad \text{(Eq. III-3)}$$

where Q represents the standing crop of litter and k is in units of days^{-1}. The parameter "k" is the turnover rate of the material, and is a function of the activity levels of the decomposer populations.

We set out parcels of natural litter exposed to the range of relatively moist and dry conditions found in the forest, and then studied the disappearance rates of the parcels. In addition, the mesh bags containing the litter parcels were of two sizes. This allowed assessment of the relative role of macro-decomposers, as accelerators of decomposition, under the paired moisture conditions. The turnover rates for leaf litter derived from this experiment by least squares regression are presented in Table III-3. All of these values are statistically significant at the 1 percent level.

There is a depression of turnover rate for both series in comparing moist to dry conditions. Under moist conditions, the macro-decomposer faunal biomass that became established within the litter bags was larger in the coarse mesh bags, thus accounting for the increased turnover rate. The amphipods, limpets, etc. that appeared in the coarse mesh bags thus accelerated the litter decomposition rate by a factor of 1.6 times. The lack of a macro-decomposer acceleration under dry conditions is something of an anomaly. We might hypothesize that fine mesh bags under dry conditions retained rain water more effectively, thus inducing a moisture gradient within the dry condition experimental series. Or, the fine mesh bags might have excluded predators that feed on the small terrestrial insects we found associated with both dry condition series. However, we lack sufficient hard data to critically evaluate either hypothesis.

Table III-3. Leaf litter turnover rates. (Based on gm dry wt of materials.)

Macro-decomposer access	Moist	Dry
Unrestricted	2.686	1.049
Restricted	1.723	1.334

In summary, we can conclude that moist conditions accelerate litter remineralization in this forest by at least a factor of 1.3, and create favorable conditions for macro-decomposers that further accelerate the process by 1.6 times.

If mineral nutrients are retained by the system while carbon is being "blown off" to the atmosphere, concentrations of nutrients will increase, making these materials relatively more available to the autotrophic layer of the community. Figure III-15 shows the concentration of total organic nitrogen (Kjeldahl method), determined for litter bags at the time of collection. The steady increase over time is presumably a consequence of the preferential release of carbon from the litter. The ratio of slopes in Figure III-15 is 0.59 and the ratio of the mean turnover rates from Table III-3 is 0.54. The more rapid turnover under moist conditions thus accounts for most of the difference.

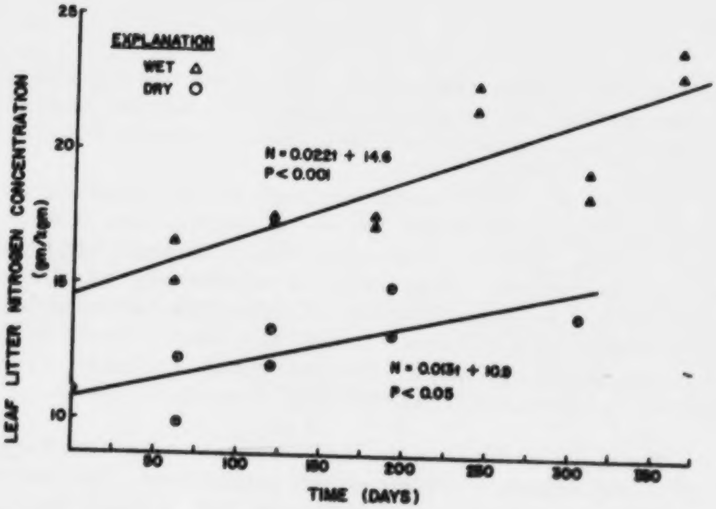

Figure III-15. Nitrogen buildup in decaying litter.

In our studies of net production in prairie ecosystems, most of the detail in our results was irretrievably blurred by wildfires that at various times burned nearly half the sites. In addition, although preliminary observations of flooded prairies in late 1971 indicated that periphytic algal growth was an important part of overall community metabolism, the prairies failed to flood in 1972. Consequently, we were unable to assess the normal level of activity of this component of the ecosystem, although we can of course state that in the absence of any appreciable hydroperiod there is, unsurprisingly, no periphyton growth.

Figure III-16 illustrates the complexity of the problem of estimating net production in prairie grasses from sequential data on standing crop. Mineral nutrients and sunlight combine (Block 1) to fix organic materials as gross primary productivity (GPP) in green leaves. Some of this material is respired directly (R_1), some is translocated to the root system, and subsequently respired (R_2), and some may appear as an increase in standing crop of live leaves. In any given interval, some leaves die and are replaced by new shoots. Leaf turnover will appear as increases in the "duff" and standing dead leaf compartment, but at the same time dead materials are being broken down by the detrital food chain and returned to the available mineral pool. When a fire sweeps through the area, if dry litter stocks are sufficiently dense (Threshold T), duff and green leaves both burn off and instantaneously build up a mineral supply in the residual ash (Block 2). Stored root stocks may then be utilized to rapidly regenerate the green leaf compartment, and the cycle resumes. The seasonal cycle of yearly die-back of the grasses and spring restoration from root storages adds still another level of complexity to the problem.

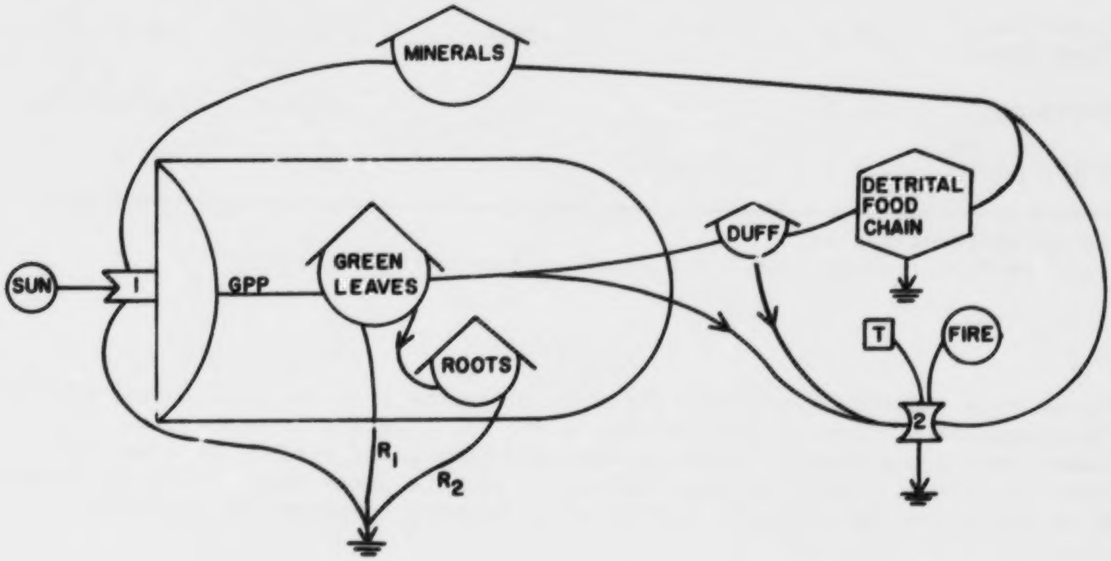

Figure III-16. Model of wet prairie production.

As a crude minimal estimate of prairie production, Table III-4 presents the differences between yearly maxima and minima in each of these compartments.

Most values in Table III-4 represent the differences between means of four determinations. Although detailed comparisons are not possible, note that production values approach those listed above for cypress strands. The frequent

Table III-4. Summary of biomass accumulation in wet prairie ecosystems based on peak-to-peak harvest values. (gm ash free dry wt/m^2)

Soil type	Leaves	Duff	Above ground Sub-total	Roots	Total
Ochopee marl,[a] Deep phase	206.6	84.8	291.4	196.6	488.0
Ochopee marl, Deep phase	195.9	189.9	385.5	192.6	578.4
Ochopee marl,[b] Deep phase	234.6	46.0	280.6	155.3	435.9
Ochopee marl[b]	458.4	104.4	562.8	442.5	1,005.3
Ochopee marl[b]	229.3	139.8	369.1	636.1	1,005.2

a Canal influenced site

b Fire recovery values over 4 - 5 month period during summer.

fires in these prairie sites made possible an estimate of the fuel threshold for propagation of fire (Figure III-16, Block T). "Duff", as used here, includes both loose ground litter and upright dead grass stalks, as grams ash-free dry weight/m^2. Based on observations of prairie areas that failed to sustain fire vs those that burned over shortly after biomass sampling, we find that

$$40 < T_f < 400$$

i.e., 40 g/m^2 of duff will not sustain a ground fire, but 400 g/m^2 constitutes a tinder-box.

Net production, although indicative of the levels of support available to the rest of the ecosystem from the autotrophic community, does not fully describe the dynamics of carbon fixation. Gross primary productivity (GPP) (Figure III-16), represents the total energy fixation for the ecosystem as a whole. We examined this parameter by isolating small portions of the community in a series of "bell-jar" experiments. The diel rates of carbon and water metabolism were established by input-output analysis of the community isolates (methods in Chapter XII). Estimation of true monthly mean activity rates required correction of observed values by monthly mean weather conditions. For prairie metabolism, this amounts to

$$\overline{NPP} = \frac{\bar{I} \, \Sigma \frac{NPP_o}{I_o}}{n} \qquad \text{(Eq. III-4)}$$

$$\overline{ET} = \frac{\bar{P} \, \Sigma \frac{ET_o}{P_o}}{n} \qquad \text{(Eq. III-5)}$$

where NPP = net primary production during daylight hours, I = total incident solar radiation, ET = evapotranspiration, P is pan evaporation, n = number of replicates and the subscript "o" indicates observed values. Pan evaporation rates for the coastal weather station were used for correction factors as this station location was much closer to the prairie sites. Further correction of these estimates for standing crop variation had virtually no effect on the resultant numerical values, and is therefore not reflected in the following table (Table III-5).

Table III-5. Summary of wet prairie carbon and water metabolism. Standing crop estimates are in grams ash-free dry weight/m^2. Metabolic values are in gm carbon/m^2 · day or mm H_2O/day.

Soil	Month	n	Metabolism				Chamber biomass	
			GPP	NPP	R	ET	Leaf	Duff
Ochopee marl,[a] deep phase	June	2	10.92	0.98	9.94	3.5	153	369
Ochopee marl, deep phase	Aug.	3	6.01	2.84	3.17	3.9	267	621
Ochopee marl,[b] deep phase	Aug.	1	14.50	4.61	9.89	4.1	216	40
Ochopee marl,[a] deep phase	Oct.	4	4.60	1.94	2.66	2.6	231	128
Ochopee marl[b]	Aug.	4	15.28	4.39	10.89	4.35	298	176

a Canal affected
b Burned in 1972.

The metabolic values shown (Table III-5) are for the entire 24-hour activity cycle. The basic data derived from the diel studies are in terms of production during daylight hours and nighttime respiration. The NPP shown in this table represents the balance between these two phases of the cycle. Total respiration was calculated by assuming the mean nighttime rate would hold for daylight hours as well, and GPP, gross primary productivity, is then the sum of NPP and R. Net primary productivity shows an apparent relationship to either seasonal effects, or drainage effects, within the data of the table. However, the lack of synoptic measurements fully confounds the validity of direct conclusions from the tabulated information. The evapotranspiration rates are 68, 82, and 59 percent of pan evaporative rates at the coastal station for June, August, and October, respectively. This data supports the mean value of 65 percent derived from test well diel patterns. In addition, it suggests a seasonal plant activity cycle, at least for the wet prairies, beyond the reduction in functioning caused by low potential evapotranspiration.

Evapotranspiration measures the simultaneous availability of sunlight and water, which perhaps are the two most important factors controlling the productivity of terrestrial ecosystems (Rosenzweig, 1968; Figure III-13). The measured evapotranspiration and 24-hour net production values from eleven complete diel cycles is shown in Figure III-17. The linear relationship between these variables is statistically significant at the 0.1% level, and gives a conversion ratio of 0.962 (gm C/m^2) per mm of water export. If we note that the mean evapotranspiration rate for the entire strand was 3.00 mm/day ({1,100 mm/hr}/366 days in 1972), this relationship estimates yearly net production at 548 gm C/m^2 year. Conversion of this figure to ash-free dry weight by the mole fraction of carbon in carbohydrate results in a value of 1.37 kg ash-free dry weight/m^2 year, a figure that is not greatly at odds with the minimal estimates provided by harvest data (Table III-4).

The relationship of actual evapotranspiration, as a fraction of pan evaporation, to the shallowness of the water table is given in Figure III-18. In this figure, the depth of water (Z) is derived from the well record pertinent to the date and site of operation of the metabolic equipment. Pan evaporation was taken from the nearer located weather station. An exponential model was fitted to this data because the work of White (1932, and Figure V-1) indicates its suitability. Much of the scatter in this diagram may be attributable to utilization by the plant community of field capacity water when the water table is low. Nonetheless, the fitted intercept appears accurate (1.007 vs a "true" value of 1.000), so this equation may represent the average response of the prairie community to water-table lowering.

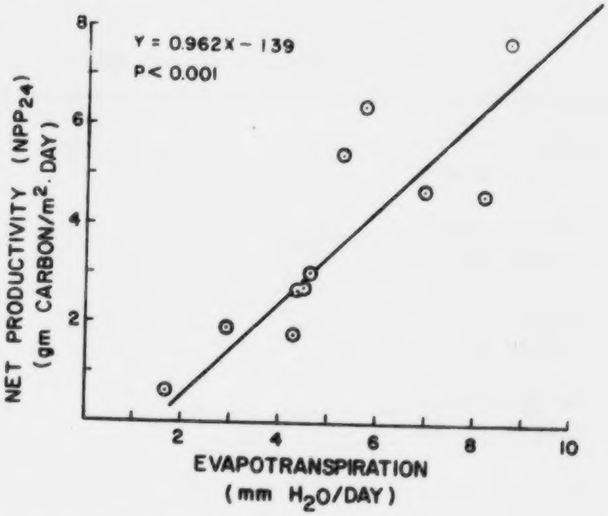

Figure III-17. Productivity and actual evapotranspiration, wet prairie.

This idea can be tested by deriving estimates of annual net primary production from the posited relationships (Figures III-17 and 18) and comparing them to the measured response of the cypress strand community to canal proximity. The mean water table depth at the test well remote from a canal (W-5, Figure III-11) was 49.8 cm. The estimated AET (actual evapotranspiration) would be

$$(AET) = (PE)\ (1.007 \exp(-0.0067 \cdot 49.8))$$

or 1,205 mm. This is in satisfactory agreement with the figure of 1,100 mm from well data, and predicts (from Figure III-17) an average net productivity of 1.78 gm C/m^2 day, or an annual net production of 651 gm C/m^2. The mean water table depth at well W-3 (0.3 km from a canal) was 90.8 cm. This figure leads to an AET of 922 mm and an annual net production of 378 gm C/m^2. The latter figure gives a 42 percent drop in net productivity due to the 42 cm water table lowering induced in the vicinity of the canal. To compare this figure to the data for cypress strands, the latter must be corrected for the difference in biomass between the two sites (Table III-2). The equivalent expression for this situation is

$$1 - \frac{(NPP/SC)d}{(NPP/SC)w}$$

where NPP is annual net production, SC is standing crop biomass, and d and w represent dry and wet sites, respectively. This expression yields a value of 41 percent for the measured drop in annual production between sites vs the 42 percent reduction for the theoretical calculation from data on net productivity, actual evapotranspiration, and water table dynamics.

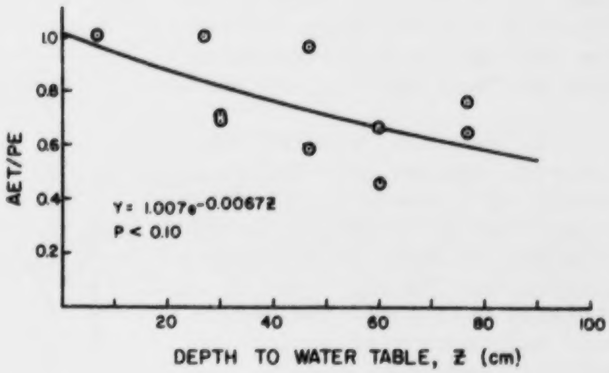

Figure III-18. Water table depth and evapotranspiration.

We can use the coupled equations of Figures III-17 and 18 to simulate the yearly cycle of production dynamics in the Fahkahatchee grassland ecosystem. Figure III-19 illustrates the (monthly mean) water table dynamics observed during 1972. The lower curve represents conditions 0.3 km (0.2 miles) from a canal, the middle curve the more normal dynamics at well W-5 (c.f. Figure III-11). The upper curve shows a hypothetical pattern, using the curve for W-5 as a base, during a year with a maximum water depth of 13 cm above ground level in the prairies. These curves, in conjunction with the mean monthly pan evaporation rates (Figure III-7) were used to generate the net primary productivity curves of Figure III-20. The correspondence of NPP with water table depth is apparent. The upper curve, which shows NPP for a year nearer the long-term average, results in a net annual production of 931.2 gm C/m^2. Using the mole fraction of carbon in carbohydrate and the mean value of 5 percent ash content for prairie leaf samples collected during the year (5.4 ± 0.4, $\bar{x} \pm 1$ SE), we can equate this figure to 2.45 dry Kg/m^2 annual production. This value can be compared to that predicted by the world wide patterns of Figure III-13, which is 2.15 kg/m^2 · year. The correspondence is quite good, and we can probably account for the difference by our neglect of the plant community activity cycle that has suggested itself at several

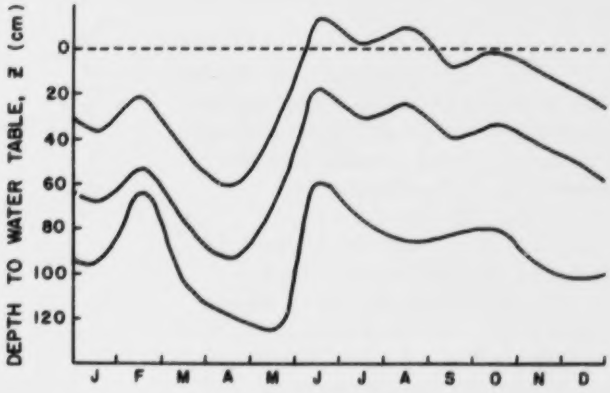

Figure III-19. Monthly mean water table depth.

junctures in this chapter. We will continue to neglect it, except to point out that the difference between late fall and very early spring NPP values in Figure III-20 probably represents the artifact in the simulation that produces the high estimate.

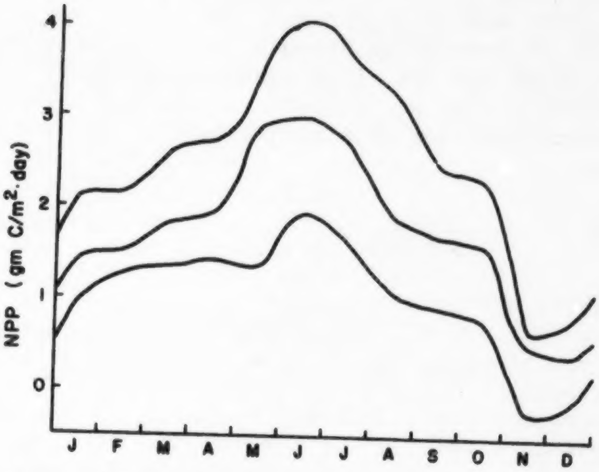

Figure III-20. Simulation of wet prairie (grass) NPP.

It should be pointed out, however, that we have still not attempted to include periphyton production in estimates of NPP. This factor would undoubtedly elevate the NPP of these prairies well above the world-wide mean during years with a normal hydroperiod.

The relationship of NPP to water table depth is shown in Figure III-21, for months when pan evaporation (PE, measuring co-availability of sun, wind, and saturation deficit) is at 100 and 200 mm H_2O/mo. The decline of NPP over the 100 cm (3 foot) range is exponential with depth, and the percent loss is more severe the more favorable are conditions for plant community production.

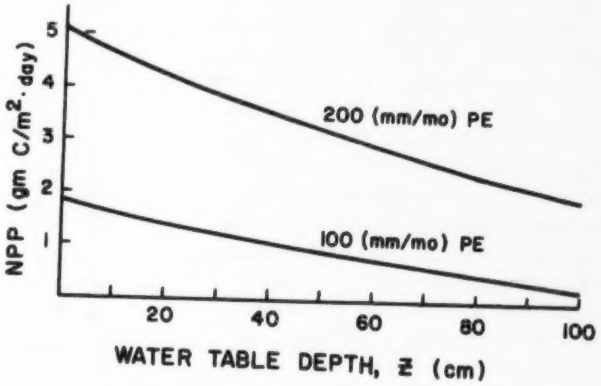

Figure III-21. NPP as a function of water table depth.

The implications of these facts for wildlife populations dependent on plant production for their food resources are sobering. Dependence of the plant community on direct rainfall for its water supply induces at the very least a 40 percent drop in NPP, which represents an equivalent drop in magnitude of the carrying capacity of the ecosystem for wildlife. The removal of ponded waters from the system eliminates periphyton production altogether, which, through the suppression of forage fish populations, may eventually severely depress the remaining bird populations dependent upon the resource during their breeding season (c.f. Kahl, 1964; Leopold, *et al.*, 1969, etc.). Some details of the forage fish populations are reported in Chapter XV.

The comparison of estuarine systems subject to artificial drainage perturbations is more difficult to assess, as a glance at Figures III-1 and 2 will show. The location map of Figure III-22 may help clarify the situation. All the water that enters Fahka Union Bay via the canal would have gone to tidewater through a mangrove zone somewhere in Collier County, but by no means

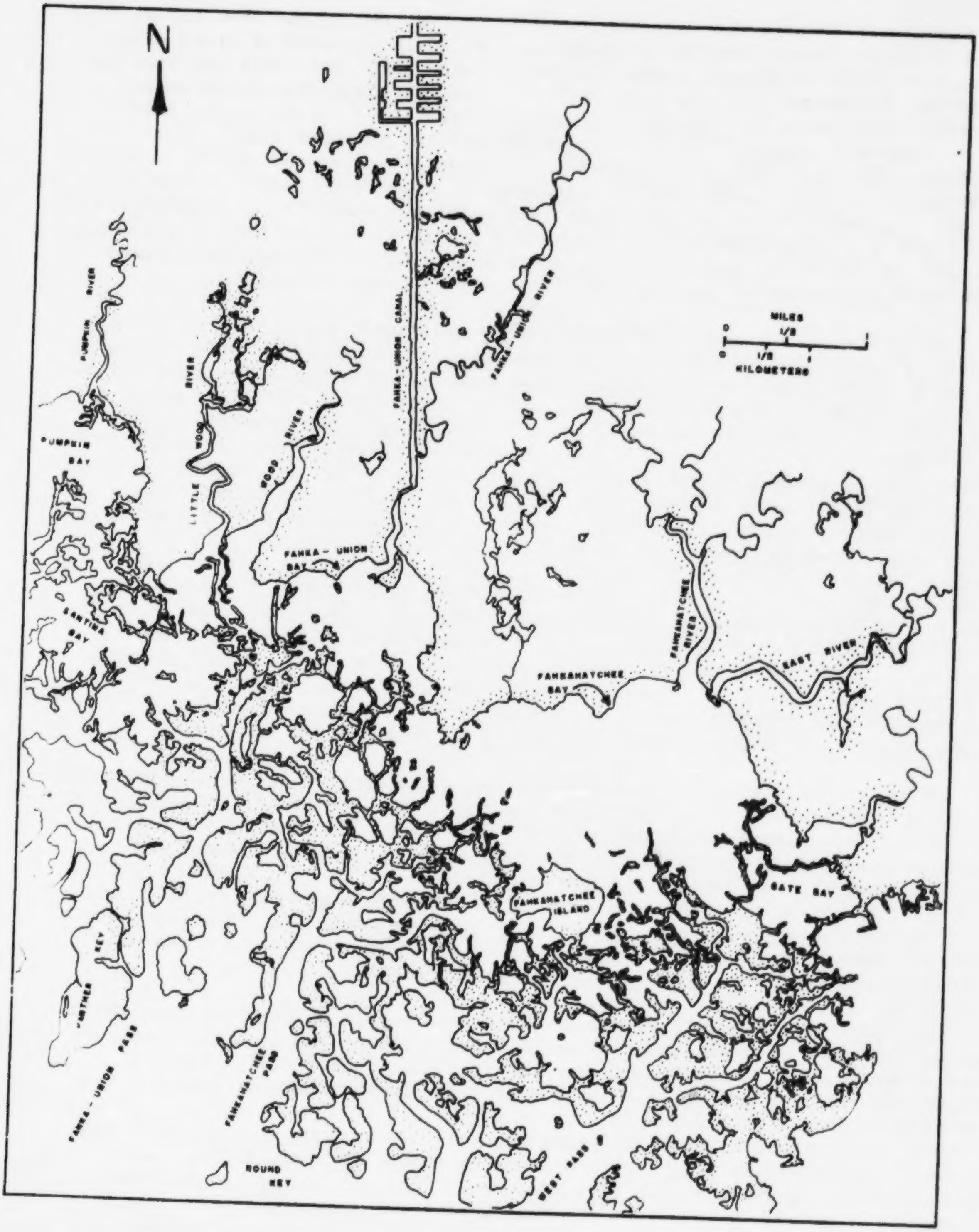
N
PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAKA - UNION CANAL
FAKA - UNION RIVER
MILES
0
1/2
1
1/2
1
KILOMETERS
FAKA - UNION BAY
SANTINA BAY
FAKAHATCHEE BAY
FAKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAKAHATCHEE ISLAND
PANTHER KEY
FAKA - UNION PASS
FAKAHATCHEE PASS
ROUND KEY
WEST PASS

Figure III-22. Map of estuary study zone.

all would pass through the Fahkahatchee estuary. To the extent that canals draw water from the strand, the Fahkahatchee Bay system is deprived of fresh water flow, some of which appears instead in Fahka Union Bay. From salinity studies conducted throughout 1972 (Chapter VII), it became evident that fresh waters entering Fahka Union Bay are partially short-circuited directly to the Gulf, and to some extent spread laterally into the insular mangrove forest south of the bays. However, the spread-out of fresh water was never sufficient to inject fresh water from the canal into the mainland mangrove forest north of Fahkahatchee Bay via the Fahkahatchee or East River (see isohaline summaries in Chapter VII). It appears that fresh waters that bypass the mainland mangrove forest, although they may appear in the waters washing the insular forest, are not back-pumped into the mainland forest by tidal action to any appreciable extent.

Phytoplankton production seems to play a relatively minor role in these estuarine bays. The bays are extremely shallow, and turbidity of the overlying waters is quite high. Resuspension of the soft bottom sediments by wind action is the major factor producing turbid waters in these bays, and is a function of the depth of the overlying water column (Chapter VIII). Phytoplankton counts were similar to those observed in other southeast estuaries (e.g. Lear and Smith, 1972). The mean depth of Fahkahatchee and Fahka Union Bays is about 1 m (3 feet). Thomas (1972) estimated phytoplankton NPP ($_{14}C$ method) to average 0.11, 0.77, and 0.54 gm C/m^3/day for April, July, and October, respectively, in Port Royal Sound, an extremely productive estuary in South Carolina. The euphotic zone in Fahkahatchee Bay, defined by the depth at which only 1 percent of incident light remains, would on the average comprise the entire water column (Chapter XII, mean k = .0237/cm). Thomas' estimates therefore can be directly transformed to an areal basis for these shallow bays. These estimates provided by Thomas' work are in good agreement with similar studies in North Carolina and Georgia estuaries (O'Hara, 1972). We can, therefore, estimate the annual mean NPP of phytoplankton in Fahkahatchee Bay at 0.5 gm $C/m^2 \cdot$ day, accounting for the higher light intensities in South Florida vs Georgia and the Carolinas.

The productivity of the marine grass and algal beds of the bay (Chapter XII) averaged 0.376 gm $C/m^2 \cdot$ day (GPP) for the year. NPP can be approximated as 50 percent of this figure, or 0.188 gm $C/m^2 \cdot$ day (Odum, 1971), over the entire bay ecosystem. This indicates that the basic food resources produced within the bay ecosystem for dependent animal populations total about 0.688 gm C/m^2/ day, or 1,870 mt/yr over the entire Fahkahatchee Bay ecosystem. Part of this would enter the animal trophic levels via a grazing food chain based on phytoplankton dynamics, and part through detrital food chains based on grass-bed leaf turnover and mortality in the grazing food chain.

To compare this in situ productivity to the inputs of detritus from the mangrove forest, we conducted studies of water movement and detrital transport over complete tidal cycles in the bay (Chapter IX). Heald (1971) found a maximum detrital export, in a similar ecosystem, in the month of November that amounted to 30 percent of yearly total export. Our study was conducted in mid-October, when export in Heald's system was only 4.3 percent of the total; but we use this 30 percent figure as a minimum estimator for calculating yearly detritus input to Fahkahatchee Bay. We convert the net transport observed (Chapter IX) to yearly values by the number of tidal cycles per year, the mole fraction of carbon in carbohydrate, and Heald's (1971) 30 percent correction. This process results in the reduction of the total resource base for Fahkahatchee Bay to common units (Table III-6).

Table III-6. Yearly resource inputs to Fahkahatchee Bay (metric tons/year).

Source	mt/yr
Phytoplankton[a]	1,360
Benthic plants	510
In situ subtotal	1,870
Mainland forest[b]	2,100
Insular forest[b]	400
Total resources	4,370

a Maximum estimate
b Minimum estimate

Net transport down the rivers accounts for system inputs derived from the mainland forest. Net transport through the passes on the south side of the bay accounts for inputs to the bay from the insular mangrove ecosystem. Bearing in mind that the *in situ* productivity is a maximum estimate and the mangrove estimate is a minimum estimate, we see that at least 57 percent of the total resource base for the bay was derived from associated mangrove forests. Under less restrictive assumptions this estimate could easily increase to 80 percent or more. The contribution of the insular forest is only 16 percent of the total mangrove forest detrital flow to the bay, even though insular mangrove forests represent 36 percent of the total mangrove forest found in the study area.

From these considerations we can see that the mainland mangrove ecosystem represents a key factor in the natural economy of the Fahkahatchee Bay ecosystem. The fate of this forest as it responds to drainage effects will largely determine the response of an estuarine bay to the loss of overland fresh water drainage. Note especially that neither tidal re-injection of fresh waters from below the forest nor compensating fresh water flow to the island mangrove forest can affect the outcome. The first does not occur to any appreciable extent, and the relative contribution of insular forests to the bay does not even match their relative share of the total forest area.

In order to examine the response of mangroves to differential fresh water inputs, we established four sites along a fresh-to-saline water gradient. Three of these sites were in the drainage basin of the Fahka Union River, which enters the Fahka Union Canal near its mouth (Figure III-22). The fourth was near the eastern shore of Fahkahatchee Bay. Community isolates, similar to those of the prairie community experiments already described, were studied for net and gross carbon fixation rates (details in Chapter XII). A result of this study is given in Figure III-23. This figure represents 14 complete diel cycles in mangrove (4 species) canopy leaves in full sunlight, normalized, as before, for mean daily insolation during the course of the complete experiment. The ordinate in this figure (R_{24}/GPP) is the total daily respiratory metabolism divided by total daily gross carbon fixation (gm C/m^2 leaf tissue · day). It thus represents the fraction of the energy budget used for direct daily maintenance expressed within the plant leaf tissue. The abscissa is the gradient in chloride concentration between the overlying water mass ($\{Cl^-\}_o - \{Cl^-\}_s$) and the soil water solution (o stands for overlying, s for soil); as a percentage of the chloride concentration in the soil water. This data was determined partially from diel studies of soil and surface salinities at the metabolism sites, and partially from synoptic survey data between the sites. We fitted an exponential relationship to this information because the supposition that the ratio (R_{24}/GPP) could exhibit negative values is logically implausible. (Negative values would imply that the respiration process was fixing, rather than releasing, CO_2). The extrapolation of this relationship much beyond the range of measurement would also be questionable, for (R_{24}/GPP) probably stabilizes at some positive value rather than continuing the slow decline of Figure III-23. Within the measured range, however, the probability of this result being due to chance alone is less than 1 in 100,000.

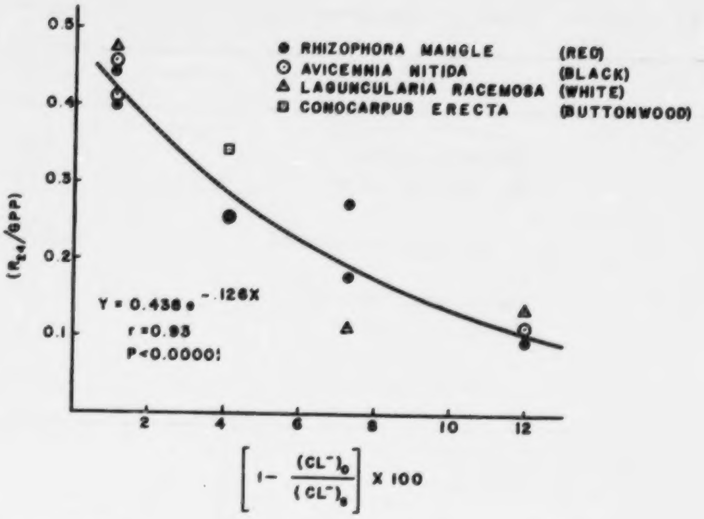

Figure III-23. Response of metabolic budget (sun leaves) to chloride dynamics.

The independent variable of Figure III-23 is an expression of the interaction between tidal dynamics and water quality within the estuarine zone. The range of possible significant interactions between these factors is rather large. For example, Bowman (1917) found it impossible to culture red mangrove seedlings on their natural soils until he adopted the habit of replacing the water in his culture vessels daily. Under stagnant conditions, the buildup of sulfide from anaerobic decomposition in the soil was toxic to the plants. This author also found a non-linear decrease in transpiration rate with increasing salinity of the plants' water supply. More recently Scholander, et al. (1955) demonstrated that tidal action serves a physical role in pumping oxygen from the atmosphere to the root systems, in both red and black mangroves. Lugo et al. (in press) have suggested that macro-nutrient availability can strongly affect the vigor of individual mangrove stands.

We might summarize some of the potential ecological factors affecting mangrove ecosystem dynamics as including:

1. Tidal factors.
    a. Transport of oxygen to the root system.
    b. Physical exchange of the soil water solution with the overlying water mass, removing toxic sulfides and reducing the total salt content of the soil water.

c. Tidal flushing interacts with the surface water particulate load to determine the rate of sediment deposition or erosion within a given stand.

d. Vertical motion of the ground water table may transport nutrients regenerated by detrital food chains into the root zone of the mangroves.

2. Water chemistry factors.

a. Total salt content governs the osmotic pressure gradient between the soil solution and the plant vascular system, thus affecting the transpiration rate of the leaves.

b. A high macro-nutrient content of the soil solution has been suggested (Kuenzler, 1969) as enabling the maintenance of high productivity in mangrove ecosystems despite the low transpiration rates caused by high salt concentrations in sea water.

c. Lugo, et al. (in press) indicate that allocthonous macro-nutrients contained in wet season surface runoff may dominate the macro-nutrient budgets of mangrove ecosystems.

While this summary is a considerable simplication of the ecological significance of water quality and tidal motion to the mangrove ecosystem, it serves to indicate the great potential shifts in mangrove ecosystem dynamics that could be induced by alteration of the natural hydroperiod.

In any case, the gradient of chloride concentration across the soil interface, expressed as a ratio to the soil water chloride concentration, may serve as an integrated indicator of the outcome of this complex dynamic process at any particular point in the estuary. Our observed data on this variable were used as the abscissa for Figure III-23.

Some effects of tidal motion in producing vertical motion in the soil water are discussed in Chapter VII. Vertical transport and tidal flushing would both decline exponentially along a transect from the bay front to the salt marsh and fresh water interface near U. S. 41. The relative proportion of phosphate and chloride in solution may serve as an adequate preliminary water quality indicator of some significance to the mangrove ecosystem. The water chemistry data of Chapter X indicate an exponential decline in the concentration of total phosphorus relative to chloride along the opposite gradient, from U. S. 41 to a point near the ocean front. Figure III-24 derived from water quality survey data for October, is representative of the contrast between the Fahka Union (canal fed) and Fahkahatchee systems. Note that in the mid-bay stations, the relative concentrations of total phosphorus vs chloride between the two systems are virtually identical. If this figure is taken in the sense of a resource utilization curve for the mainland mangrove ecosystem, it indicates that the canal system short-circuits the "chemical resource potential" of flowing fresh waters from the upland directly to the bay ecosystem, where it is rapidly dissipated by admixture with sea water. Although the insular mangrove forest may receive some benefit from this process, the resource loss from the mainland mangrove ecosystem is absolute.

We have schematized the overall interaction of tidal pumping and water chemistry, as it may affect the functioning of mangrove ecosystems, in Figure III-25. Both the tidal amplitude and the "chemical resource potential" curve show an exponential decay with distance from the source. The respiratory drain on the system may be high whenever either of these functions is at a low level.

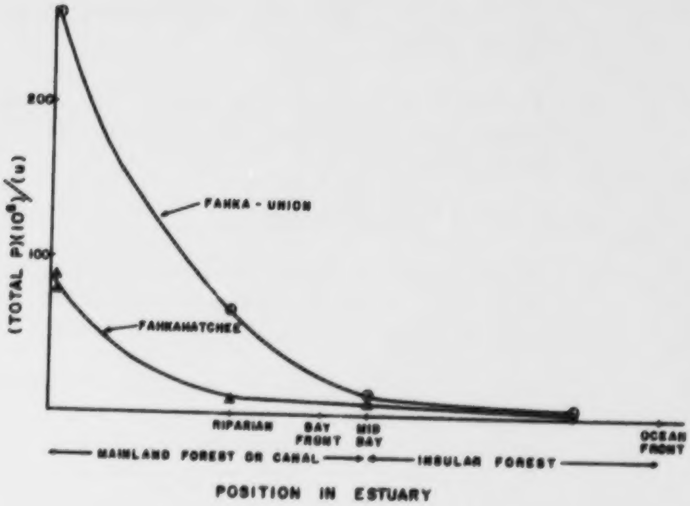

Figure III-24. Fresh water dynamics.

If so, we can expect that the fraction of the mangrove ecosystem budget that is devoted to immediate needs, (R_{24}/GPP, Figure III-23), could be related to the sum of the reciprocals of the functions shown in Figure III-25. This would predict that (R_{24}/GPP) should show a generally U-shaped response curve according to position in the estuary. Salinity of the surface water mass served as an adequate indicator of position during a synoptic survey of surface water chloride concentrations at the metabolic study sites. Hence, in Figure III-26, we show (R_{24}/GPP) as related to position or surface water chloride concentration. The pattern in this figure accords fairly well with expectation. However, this is at best a fairly rough approximation of an extremely complex situation.

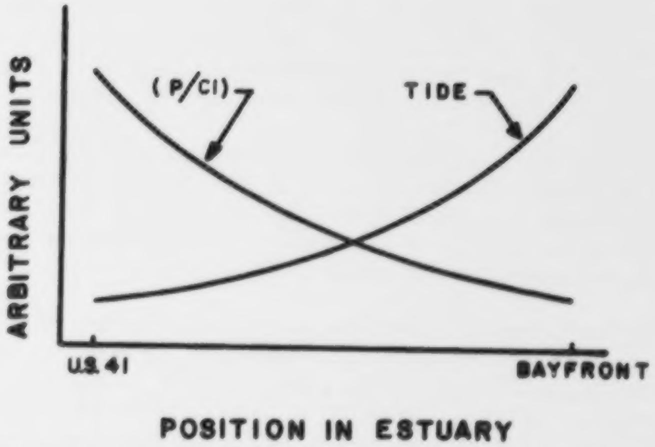

Figure III-25. Spatial distribution of tidal flushing and sweet water.

Some preliminary estimates of salt marsh and mangrove community metabolism are presented in Chapter XII. In general, these results support the conclusion of Lugo, et al. (at press) that zonation of mangrove communities has a strong metabolic correlative that may help explain the related competitive abilities of the several species of mangroves in their respective zones of dominance. The data of Chapter XIII indicate that this concept may supply equally well to salt marsh communities. Although the evidence is not conclusive, it seems that the loss of overland fresh water inputs to the well developed mangrove forests of southwest Florida will at least induce shifts in the community structure of these forests. The impact of these shifts on the detrital-based economy of the lower estuary would then depend upon the relative litter production of the several species and the transport dynamics of the mainland mangrove ecosystem.

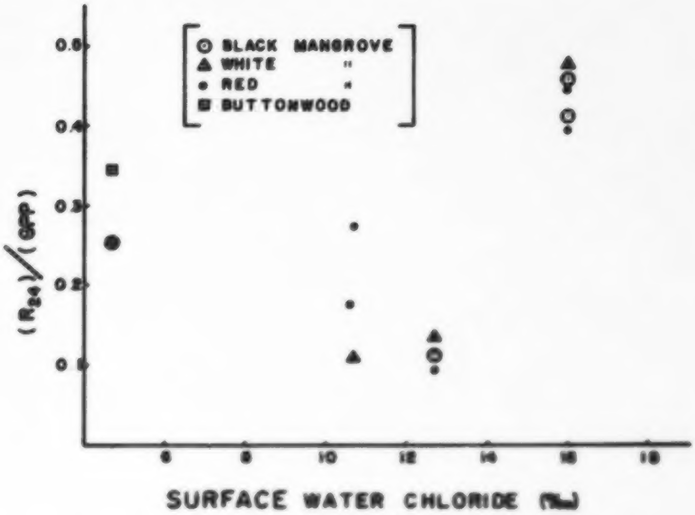

Figure III-26. Spatial response of metabolic budget.

IV INTRODUCTION

GENERAL

The decade ending in 1970 may well be remembered as "the beginning of the end" for south Florida. Portions of south Florida had growth rates reminiscent of the 1920 boom days in Miami. From 1960 to 1970 Collier County was the fifth fastest growing county in the United States with an increase in population from 15,753 to 36,568 or 132 percent. At the present time there are no indications that the growth rate will not continue to "snowball". Based on expectations of the major developers and industries in Collier County, the 1970's will surpass the 1960's in growth.

Several surveys (Hawkins, 1972; Candeub, Fleissig and Associates, 1973) indicate that Collier County will grow in population from the present 40,000 to 200,000-250,000 in the next 14 to 27 years. Land is being sold which normally is under water from fifty to ninety percent of the time. Upon visiting the site of their retirement home, retirees are often dismayed at what they find. Because of salinity barriers, access to the Gulf is not possible. Drainage canals are often choked with dense vegetation. Adequate county roads are few. The cost of providing telephone service to these remote areas is horrendous -- running in the thousands of dollars. Municipal water supplies and sewage treatment facilities are often unavailable.

Areas which were once highly productive are now drained. Vast mangrove forests have been cleared and filled for homesites and commercial developments. Tidal streams have ceased to flow because of bulkheads. Public access to beaches is being curtailed by oceanfront condominiums and apartments. The use of pesticides is threatening to upset the delicate balance of nature and to eliminate entire species of animals.

What is the fate of the south Florida wilderness known as the Big Cypress Swamp, the Everglades and the Ten Thousand Islands? Will man and his greed for material possessions destroy these unrestorable resources for a short-term monetary gain? Or will the State or Federal Government, in their attempt to preserve or protect these areas, impose such stringent regulations as to prohibit all growth in south Florida? Somehow there must be an accomodation between developers and conservationists. Man and nature have lived in union for many thousands of years, and if both are to survive, man must realize that he is but a small part of nature, and must not disrupt the vital organs of his ecosystem.

This study examined the intricate relationships existing between the various components of natural and disturbed ecosystems existing within the Big Cypress Swamp and the Ten Thousand Islands. With a quantitative knowledge of these inter-relationships, predictions may be made concerning the dependence of one ecosystem upon another. With this knowledge county commissioners and other decision makers in south Florida will be able to extend their decision criteria beyond conflicting pressures from special-interest groups within their constituencies and their own intuitions of the general public welfare.

BACKGROUND

In September 1968, the Dade County Port Authority began construction of a 39 square mile jetport six miles north of Everglades National Park and on the edge of the Big Cypress Swamp. No environmental studies preceded the selection of the site, and, although the Department of the Interior had expressed concern for the effects of the jetport on Everglades National Park, the Miccosukee Indians and the Big Cypress Swamp, final announcement of the selected site and start of construction was learned through the news media. With a definite knowledge of the site, Interior's fear for the future of Everglades National Park, the Big Cypress Swamp and the Miccosukee Indians increased. Interior and the Department of Transportation agreed to study the problem. The study produced a report (U. S. Department of the Interior, 1969) prepared by an Interior team of specialists under the direction of Dr. Luna B. Leopold of the U. S. Geological Survey. The findings and recommendations of the report are summarized below.

> Development of the proposed jetport and its attendant facilities will lead to land drainage and development for agriculture, industry, housing, transportation and services in the Big Cypress Swamp which will inexorably destroy the south Florida ecosystem and thus the Everglades National Park. There are three alternatives for future action:
>
> 1. Proceed with staged development of training, cargo, and commercial facilities. Regardless of efforts for land-use regulation, the result will be the destruction of the south Florida ecosystem. Estimates of lesser damages are not believed to be realistic.
>
> 2. Proceed with final development and use of a training facility of one runway, with no expansion for additional use. Obtain an alternative site for expansion, probably through an exchange of excess lands at the current site for public lands at a new site. Permit no new or improved surface access to the current site. This alternative would not preclude eventual development of lands in the vicinity of the current site. It could, however, reduce pressures for development and secure time for the formation of sufficient public interest in environmental conservation to achieve effective planning and land-use regulation.
>
> 3. An alternative site be obtained capable of handling the training operation as well as the fully developed commercial facility; and that when appropriate, the training activities at the present site be abandoned and transferred to the new site. Permit no new or improved surface access to the current site. This would give an impetus to developing effective land-use controls which could lead to permanent protection of the south Florida ecosystem.

In arriving at these recommendations, the study team came to a number of conclusions regarding the impact of the jetport on the environment of south Florida and on the general effect of development on the natural conditions of any area or region. On the basis of the report, Secretarys Hickel and Volpe agreed that an alternate site should be selected and that the single-runway training strip could operate, with stringent environmental controls, until the alternate site was selected. On January 15, 1970, the White House announced that an agreement (The Everglades Jetport Pact, 1970) had been made with the Dade County Port Authority and the State of Florida whereby the jetport would be moved to a more desirable location.

Under the terms of the agreement (Jetport Pact) signed on January 16, 1970, between the Departments of Interior and Transportation and the State of Florida, and the Dade County Port Authority, the Port Authority agreed to begin immediately a search to relocate the commercial airport away from the planned site in the Big Cypress Swamp area adjacent to the Everglades.

The agreement also provided that the facilities already constructed on the site would be used only as a single-runway airport for flight training purposes and that such operations would be carried out under strict environmental safeguards designed to protect the Everglades National Park and the Miccosukee Indians. Such training facilities would eventually be transferred to the alternate commercial site.

The two Departments agreed that Dade County would not be required to abandon the current airport site until an alternate site had been agreed upon and acquired without cost to Dade County, and training facilities substantially equivalent to those existing at the present airport had been constructed on the site without cost to Dade County.

The agreement, recognized the need for a south Florida regional airport, the construction of which must be completed before the end of the coming decade, was effective for three years and was subsequently extended for a two-year period ending January 16, 1975. This extension was primarily to allow the parties to complete their obligations pertaining to the selection of an alternate airport site. The agreement provided that the Department of the Interior would undertake a comprehensive program to determine the present condition of the environment, and monitor the effect of operations at the training airport.

Dade County agreed that it would not construct additional runways, taxiways, buildings, structures, or facilities of any type, except as required for fire, rescue and security purposes and would not improve or extend the use of the existing facilities already in place at the airport.

The Interior Department agreed to provide recommendations for uses of the Big Cypress Swamp, while Dade and Collier Counties agreed that they would control, limit, and restrict all drainage in the Big Cypress Swamp area until a comprehensive land use plan was agreed to among all parties.

Pursuant to the agreement between the United States (Department of Transportation and Department of the Interior) the State of Florida, and the Dade County Port Authority, the Secretary of the Interior agreed to perform the following tasks: (1) Provide site criteria for locating an alternate jetport site for south Florida and apply the criteria to the site offered for evaluation; (2) Establish an environmental monitoring program for the area affected by the presence and use of the existing jetport site; (3) Undertake the planning, development, and coordination of an ecological study of the region, including its hydrology, and providing recommendations for uses of Big Cypress Swamp, which would be consistent with preserving and protecting the environment and ecosystems of Everglades National Park, the water supply of the affected communities and the marine resources of dependent estuaries.

The foregoing programs were accomplished as a joint effort by five bureaus in the Department of Interior (National Park Service, Geological Survey, Bureau of Sport Fisheries and Wildlife, Bureau of Outdoor Recreation, and the Bureau of Indian Affairs) and two former bureaus, the Federal Water Quality Administration and the Bureau of Commercial Fisheries, now transferred to the Environmental Protection Administration and National Oceanic and Atmospheric Administration, respectively, under the direction of the Everglades-Jetport Advisory Board composed of directors of each participating bureau and agency. The director of the National Park Service was designated Chairman of the Everglades-Jetport Advisory Board and the National Park Service was directed to coordinate the program.

Public concern and pressure forced the jetport to abandon its Big Cypress location. The problem which forced the abandonment was not the direct effects of the jetport itself, but the uncontrolled growth, with its inherent problems around the periphery of the jetport. However, that very problem now appears in other portions of the Big Cypress and Ten Thousand Islands. Massive growth patterns are evident in western Collier County and are continuing easterly. Potential sites include developments in Gum Slough, Marco Shores, and Ochopee.

OBJECTIVES

The overall objective of this study was to obtain the necessary technical information for objective planning of a program for wise use of the natural resources of south Florida's land, water, wildlife and fisheries. To accomplish the objective it was necessary to predict the impact of different types and levels of human activity on the characteristics of various south Florida ecosystems.

The strategy selected was to obtain detailed knowledge of the intricate inter-relationships existing between the various components of ecosystems presently subject to a minimum of external perturbations resulting from human activity. This detailed knowledge was used to formulate process studies and experimental manipulation models for the various components of the ecosystem. These models were then used for predicting some effects on the systems of various inputs of change which could result from differing types and levels of land use. These predictable effects are applicable to much of the remaining undisturbed areas throughout the south Florida region which are ecologically similar.

Concurrently in gathering information for the systems analysis and modeling program, a detailed characterization of the study area was made. This includes background data on chemical quality of waters and sediments; pesticide levels in water, sediments, fish and higher animals; and life history aspects of several freshwater and marine fishes, especially the much sought after snook. Several detailed studies relating to man-made changes to the environment were conducted. These include salinity variations in natural versus man-influenced estuaries, variations in benthic communities in natural versus man-influenced estuaries, and the effects of canals and other drainage on ground and surface waters.

SCOPE

In order to accomplish the stated objectives, a decision was made to conduct an in-depth study of a representative area of the Big Cypress Swamp. Logistics and time limitations prohibited studying the entire south Florida region. The selected study area was Fahkahatchee Strand and contiguous areas including the bays and estuaries to the southwest.

The major biological and ecological balance of south Florida is predicated upon the hydroperiod. Because of the dependence of response patterns of many species of flora and fauna on the complete cycle of the hydroperiod, it was initially intended that all phases of the study be conducted over a minimum one year period. However, because of late arrival of some equipment, the minimum one year period could not be met for all portions of the study. With the exception of plant community productivity, all segments of the study were conducted and completed as scheduled from October 1971 through January 1973.

AUTHORITY

The authority for the South Florida Ecological Study is a combination of a Secretarial directive (Department of the Interior), normal Department of Interior authorities and interagency memoranda of understanding, and a specific appropriation by Congress. The National Environmental Policy Act of 1969 (PL-190, enacted January 1, 1970) sets forth policy and concepts on which the South Florida Ecological Study was based. The purposes of the Act, in addition to establishing a National Environmental Council, are to declare a national policy which will encourage productive and enjoyable harmony between man and his environment, to promote efforts which will prevent or eliminate damage to the environment and biosphere, to stimulate the health and welfare of man, and to enrich the understanding of the ecological systems and natural resources important to the Nation.

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V - DESCRIPTION OF STUDY AREA

SOUTH FLORIDA

The vast peninsula of south Florida possesses many features that are unique among American landscapes. First, it is a land that has been created entirely through the efforts of living creatures. Neither the potent geological forces that built the great mountain chains of the West, nor the patient weathering of rocks by wind and water that eroded the Appalachian chain of today's green hills, are anywhere in evidence. Instead, the foundation rock of Florida is limestone, the result of million of years of activity by marine plants and animals.

The landscape occupying this limey platform is equally unusual, and an equally unique creation of the living world. The immense sweep of the sawgrass plains of the Everglades and the fingering sloughs of the Big Cypress Swamp are geologically very young. The area around Everglades National Park emerged from the sea only 5,000 years ago, and the sawgrass plains just south of Lake Okeechobee were marine meadows just 20,000 years ago (Craighead, 1971). As the land emerged from the sea, it provided opportunities for colonization to two very different groups of plant and animal life. North American temperate zone species began to move down the Florida peninsula into the newly created land, and tropical plants and animals of the West Indies region began to arrive from the south. For the tropical species, Florida was the end of a long chain of tropical islands ultimately connected to the mainland forests of South America; the last island south of the zone where winter frosts destroy life and require a yearly cycle of springtime renewal. The temperate species' invasion of Florida was not hampered by ocean barriers, but they may have encountered difficulties in competing successfully with the better adapted animals and plants from the south.

The biological communities of south Florida today reflect the current state of this continuing process. For example, the populations of large mammals (white-tail deer, bear, cougar, raccoon) are derived from the north, for the Florida current has prevented the migration of large tropical mammals to Florida. In contrast, about 61 percent of the plant species are of tropical origin, and 91 percent of these are species that occur in the Caribbean area (Long, R. W., and O. Lakela, 1971). Perhaps the most spectacular example of this mixture occurs in the Fahkahatchee Strand of the Big Cypress area, where native tropical royal palms exist side by side with bald cypress and swamp hardwoods that are widespread throughout the Southeastern United States. Although ultimately these newly emerging ecosystems were to generate one of the largest swamp and marshlands in the world, some major initial difficulties had first to be overcome, primarily in terms of the special nature of the local climate.

The climate of south Florida is broadly similar to that of oceanic islands. Winter temperatures are mild, but the rainfall pattern throughout the year is somewhat erratic. During the summer months, thunderstorms march across the landscape and occasional hurricanes move in from the Caribbean; during the winter the weather regime becomes a long succession of cloudless balmy days broken by sporadic breakthroughs of cooler weather from the north. Thus, the rainfall regime is marked by a summer rainy season from May through October and a five month winter dry season. At first sight then, the pattern of water availability in south Florida seems similar to that of more northerly areas of the United States, where winter rains are locked up in snow and ice and do not become available to plants until much later in the year. Here, however, another factor enters the picture: the extreme lack of topographic relief within the south Florida basin. From Lake Okeechobee to Florida Bay the seaward slope of the land averages only about two inches per mile (3 cm/km). As a result, the flow of fresh water towards the sea is extremely slow and the local thunderstorms spread a sheet of shallow water over large areas. Under these restricted drainage conditions, dead plant material falling into the shallow ponded waters is not readily decomposed, and thick deposits of organic peats and muck soils gradually build up. The latest pattern that emerged (Parker, 1955; Davis, 1943, 1946) was a vast basin of swamp and marsh communities whose soils acted as a gigantic saturated sponge, absorbing the summer rains and slowly releasing water during the winter drought season. The importance of the development of this water storage capability to the biological communities of the south Florida region (including man) cannot be overestimated. Florida lies in the latitudinal belt of the great deserts of the world. If we add the maritime effect of the Atlantic and Gulf water masses, consideration of rainfall and temperature patterns leads to the conclusion that south Florida's natural landscape should be a "tropical savannah" (Hela, 1952). The sweeping plains of Africa dotted with acacia and baobab trees are the best known example of this kind of ecosystem; it is characterized by a long parched dry season and lack of enough rain during the rainy season to make up losses in evaporation and transpiration. During the dry season, life for the human members of these communities is very difficult indeed, and both plant and animal communities are very unlike what we see in south Florida today.

The variability within the average pattern is an important aspect of the rainfall regime, and contributes to the need for water storage in any given environment. Deserts are relatively lifeless not merely because they are plagued by a low average rainfall (250 mm (10 in) or less), but because the rain is so variable - some years it may not rain at all. The areas of North America that support major human populations have mean annual rainfalls ranging from 250 mm (10 in) to about 2,000 mm (80 in). The "coefficient of variation" (ratio of variability (standard deviation) to the mean, $s/\bar{x}$) varies from as low as 0.1 for well watered regions to as high as 0.5 for the arid regions (annual values) (Fair, Geyer, and Okun, 1966). This means that a year with a rainfall deficiency as great as half the mean annual rainfall will occur in arid regions as often as a deficiency of only one-tenth the mean in better watered areas. If a stable consumptive-use pattern is to be maintained, high values of the coefficient of variation signify that high storage requirements exist and must be met simply to compensate for variation within the average water-supply pattern. In other words, even when the overall pattern of water use is in balance with the average supply, large populations of organisms cannot be sustained in the absence of suitable "filters" to eliminate environmental "noise".

The available rainfall records for south Florida covering the period from 1825 to 1968 have been collected and analyzed by T. M. Thomas (1970). These show that the coefficient of variation (c.v.) for annual rainfall amounts to about 0.2 throughout the region. However, the variation on a month by month basis is rather different. During the dry season, the c.v. runs from 0.75 up to values greater than unity, and wet season months show values from 0.3 to 0.7. A concrete example will serve to make the situation clear: for Everglades City, in Collier County, the mean annual rainfall is 1,371 mm

(54.41 in) over the period from 1931 to 1972, with a c.v. of 0.19. If we choose January and July to represent the dry and wet seasons respectively, we find that the rain varies from a low of 0.5 mm (.02 in) for January, 1950 to 173 mm (6.81 in) in January of 1958, with a mean for 1931 to 1972 of 42.2 mm (1.66 in). The equivalent range for July is from 69.8 to 443.2 mm (2.73 - 17.45 in) on a mean of 209.8 mm (8.26 in). The coefficient of variation for January is 1.0, for July values 0.4.

The total pattern that emerges is one of a regularly recurring wet and dry season, with a highly variable detailed pattern of month by month delivery imposed upon it. It is not our purpose here to make detailed comparisons of south Florida with other areas of the country. Indeed, the month-by-month variation in precipitation may in many regions be as great or greater than is the case for south Florida. However, south Florida ecosystems are unique in the extent to which the biotic community has developed an intrinsic water reserve system in its massive organic peat and muck deposits. This appears to have completely removed precipitation variability as a factor affecting water availability to the ecosystems of this region. The weight of the currently available evidence seems to indicate that environmental predictability is a major factor in determining the diversity of biological communities (Slobodkin and Sanders, 1969). Total abundance of organisms, by contrast, may be a function of the size of the total resource base and the general rigor of the environment. The lush ecosystems of south Florida are sustained by an interaction of favorable conditions from both sides of this ledger. Moreover, Futuyma (1973) has argued that highly diverse communities may be especially unstable in the face of environmental perturbations, in the sense that perturbation may produce irreversible changes in the species composition of the ecosystem. He summarized the implications of his argument as "the bigger they are, the harder they fall".

These effects sum up to the imposition of a necessary water storage capacity as a condition of survival for south Florida ecosystems. The apparent superabundance of water in south Florida is an illusion engendered by the efficiency of ecological systems in storing water for subsequent utilization in biotic processes of growth and reproduction. Without belaboring the point, we should also point out that this mode of storage can be highly efficient in terms of isolating the storage reserve from the evaporative driving forces of sun, wind, and saturation deficit. Figure V-1 shows the exponential decline in evaporative water loss (expressed as a fraction of the potential water loss from a free water surface) as the water table falls below the surface of the ground (from Todd, 1959; after White, 1932). The advantages over storage as surface water in lakes and reservoirs are apparent, for a lake will, of course, continue to export water to the atmosphere at the free water surface rate. In the case of a cypress slough there is an additional factor: the cypress trees drop their leaves sometime around November, and do not leaf out again until March, so the biological transpiration drain on the reserve system during the dry season is very small. Considerations of this sort led Odum, et al (1972), to recommend that the city of Naples control development of a cypress slough within the city limits so as to retain its essential characteristics as a water conservation tool.

The successional pattern of development of these peat and muck soils is one of gradual increase in the thickness of the soil layer up to a point where it comes into equilibrium with the surface water supply. Thereafter, the increments of dead plant matter added during the wet season are decomposed by biochemical oxidation when the surface layers are exposed during the following dry season. The inorganic nutrients that are regenerated by and large remain in the soil, and the plant carbon is returned to the atmosphere as CO_2 gas.

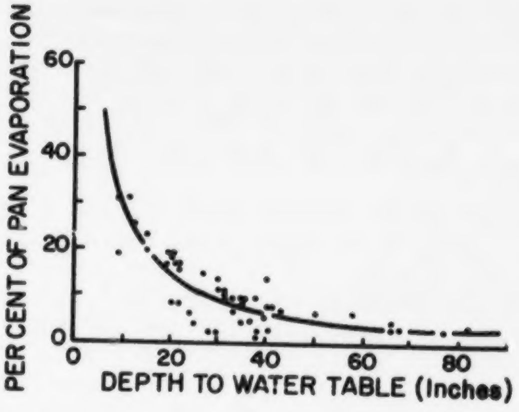


Figure V-1. Ground water evaporation, expressed as a percentage of pan evaporation, as a function of depth to the water table (from Todd, 1959; after White, 1932).

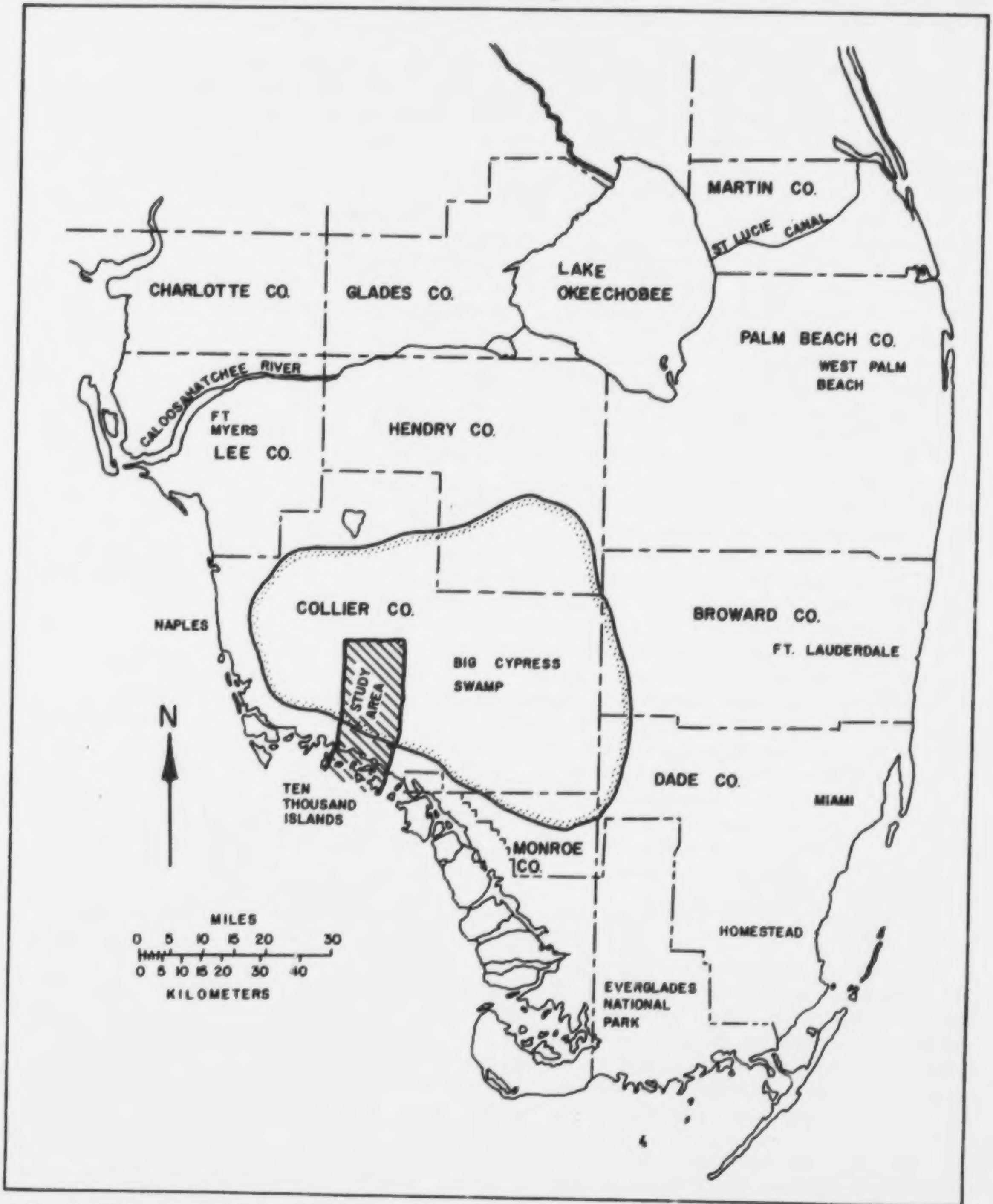
At this point it is worth recalling that quasi-mechanical analogies, however useful in organizing our thinking, ultimately break down when we are dealing with complex biological systems. An ecosystem should be regarded as a living synthesis of the opportunities and restrictions imposed by nature at a given place and time, and in a sense it continuously recomputes its trajectory toward future states of the system as these conditions fluctuate. Furthermore, in the face of abrupt shifts in environmental conditions the ecosystem sends out many feelers, as it were, toward new possible states; with the most probable end point defined by the novel complex of plant and animal populations best adapted to the new conditions. This situation has led to the introduction in ecology of a number of descriptive terms for these states and processes. "Primary succession" refers to the initial development of a biological community from a more or less sterile initial point; this is the process described above for south Florida. "Secondary succession" refers to the process of restoration that follows a major local disturbance when environmental conditions are not changed, for example, regrowth of a mature forest after a logging operation. The "climax" state refers to the developmental endpoints of the successional process, and may be of several types. Most notably, the "climatic climax" is the ecosystem type dictated by climatic conditions, for example, tropical rain forests or arctic tundra. "Edaphic" climaxes are states of arrested succession or local endpoints of ecosystem development dictated by special local conditions, for example, unusually high concentrations of heavy metals in the soil or regular dry season fires.

In south Florida continuing succession beyond the primary stage described above has developed a mosaic of pine forest, cypress strands, hardwood hammocks, coastal mangrove forest and salt marsh, sawgrass plains and wet prairies. The role of edaphic factors, especially seasonal fires and soil depth, has been described by several authors (e.g. Egler, 1952, Craighead, 1971). In general, the climatic climax of the region appears to be hardwood forests, and perhaps cypress forests in deeper runoff "channels". The pine forests, sawgrass plains, and wet prairies are maintained by a combination of shallow soils and periodic light fires of sufficient intensity to kill the seedlings of broad-leaved woody plants but not the grasses or pines. Sawgrass, for example, will often sustain a prairie fire when there is still five centimeters of water standing above the surface. The roots and peat soil thus remain undisturbed, but invading shrubs are all killed. Whether eventually the sawgrass Everglades and Big Cypress prairies would have given way to vast forests of cypress, pop ash, mahogany, gumbo limbo, and maple will never be known, for residential and agricultural development, for good or ill, began a process of drainage throughout the region that has profoundly changed the conditions of existence for most of the ecosystems of south Florida.

All organic soils lose surface elevation, or subside, when drained. Stephens and Speir (1969) have summarized experience with this phenomenon in south Florida and made comparisons to other areas of the world. In the Everglades, the peat and muck soils have a subsidence rate of 3.05 cm per year after initial settlement. The loss of soil at a stone monument at the Everglades Agricultural Experiment Station from 1924 to 1968 has amounted to 1.6 meters (5.25 ft). Stephens and Speir (1969) predicted that, based on the overall soil loss pattern, this great winter vegetable growing zone will be useless for agricultural purposes by about the year 2000. Recently some growers in the region have been flooding their fields during the non-growing season to delay this endpoint, but the process cannot be halted, only slowed. The loss of soil when the water table is lowered by drainage is of course only the natural process of biochemical oxidation that formerly kept the peat level in equilibrium with the natural water supply, writ large. But for the ecosystem it is an abrupt change in the conditions of existence that entrains the forces of ecosystem succession toward a new endpoint whose outlines can be only dimly perceived. Attempts to ameliorate the initial destructive changes that have excited the public imagination have further confused the picture. Secondary shifts of water balance, through the development of water conservation pools and timed releases to other areas, have imposed still newer forces on the transient states already induced by drainage. We are left with a myriad of small scale experimental attempts by the ecosystem to adjust to new conditions, but with very few scientific criteria for predicting or controlling the overall outcome, and with still fewer ideas as to what would constitute a desirable or ideal final endpoint. One possible endpoint is clear, the tropical savannah imposed by the basic climatic regimen. This prospect, one of summer floods, followed by a parched winter dry season marked by acute water shortages as uncontrollable wildfires sweep the basin, is uniformly held to be undesirable. Man today controls almost all the water that flows in the south Florida basin, but our efforts thus far to manage it for the good of all have had grisly side effects. During the drought of the early 1960's, more than half the alligator population of Everglades National Park perished when the flow of water from the water conservation areas to the north was cut off to maintain the city of Miami's water supply (Craighead, F. C., Jr., quoted in Caulfield, 1970).

Conversely, more recently the southern parts of the conservation pools and the Loxahatchee wildlife area have been invaded by purely aquatic and pond ecosystems as water levels have deepened. What has been missing is not good will, nor energetic measures ingeniously applied, nor the willingness to try new solutions for novel problems. Rather we simply do not understand in sufficient depth or detail the ways the past ecosystem built its own water supply system; nor a detailed knowledge of the ecological processes that we might enhance to prevent the destruction of the south Florida landscape in toto as we use parts of it for our own economic and human ecological purposes.

As part of the South Florida Environmental Study, the Environmental Protection Agency (EPA) decided to try to improve our knowledge of the functioning of natural south Florida ecosystems and their initial responses to drainage by a concentrated effort in one relatively restricted ecosystem unit. The Fahkahatchee Strand and its associated wet prairies, salt marshes, and mangrove lined estuary was chosen for this purpose. Altogether, the study area (Figure V-2) comprised 460 square kilometers (177 sq mi), mostly in the Big Cypress and wholly within Collier County.



MARTIN CO.
ST LUCIE CANAL
LAKE OKEECHOBEE
CHARLOTTE CO.
GLADES CO.
PALM BEACH CO.
WEST PALM BEACH
CALOOSAHATCHEE RIVER
FT MYERS
LEE CO.
HENDRY CO.
COLLIER CO.
NAPLES
BROWARD CO.
FT. LAUDERDALE
STUDY AREA
BIG CYPRESS SWAMP
N
TEN THOUSAND ISLANDS
DADE CO.
MIAMI
MONROE CO.
MILES
0 5 10 15 20 30
0 5 10 15 20 30 40
KILOMETERS
HOMESTEAD
EVERGLADES NATIONAL PARK

Figure V-2. General location map of the Big Cypress Swamp and study area.

BIG CYPRESS SWAMP

The Big Cypress Swamp is located in Southwest Florida within the Floridian section of the Coastal Plain province (Figure V-2). Portions of Collier, Lee, Monroe, Dade, Broward, and Hendry Counties are included in the 6,340 square kilometers (2,450 sq mi) of the Big Cypress Swamp. The Ten Thousand Islands serve as the southwest boundary of the swamp.

Much of the Big Cypress Swamp is less than 4.9 meters above mean sea level. The slope of the land surface is generally south to southwest and varies from 8 to 16 cm/km (5 to 10 inches/mile). Natural drainage of the land is slow. The swamp contains many small depressions or "potholes" which have no surface drainage. These provide the only source of surface water during droughts. Large areas covered by small to medium cypress trees, swamps containing large cypress and deciduous broad leaf trees, pine islands, and wet prairies are characteristic of plant communities in the region. Some noteworthy cypress strands and swamps include Fahkahatchee Strand, Corkscrew Swamp, Camp Keasis Strand, Kissimmee Billy Strand, and Wilson Strand (Leighty et al, 1954) (Figure V-3).

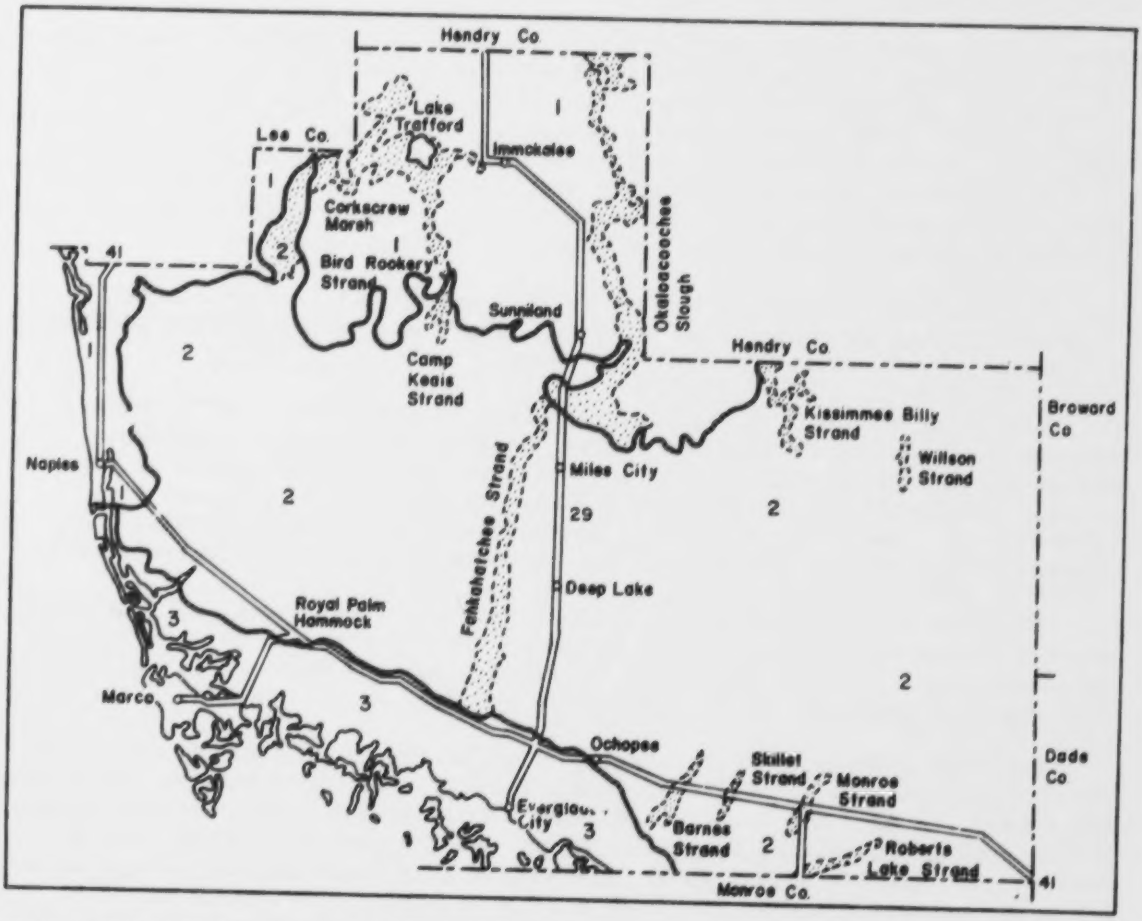

Hendry Co.
Lake Trafford
Lee Co.
Immokalee
Corkscrew Marsh
Bird Rookery Strand
Sunniland
Okaloacoochee Slough
Camp Keais Strand
Hendry Co
Kissimmee Billy Strand
Broward Co
Wilson Strand
Naples
Miles City
29
Fahkahatchee Strand
Deep Lake
Royal Palm Hammock
Marco
Ochopee
Skillet Strand
Monroe Strand
Dade Co
Everglades City
Barnes Strand
Roberts Lake Strand
Monroe Co.
41
1
2
3

Figure V-3. Major strands of the Big Cypress Swamp.

The Ten Thousand Island chain extends from Gordon Pass (South Naples) southeastward for about 64 kilometers (40 miles) along the southwest coast of Florida. This low coastal region features many tidal rivers, bays, lakes, and thousands of small islands. Much of the area is covered by mangrove swamps and salt-water marshes. Chokoloskee Island, consisting chiefly of ancient shell mounds made by pre-Columbian Indians, and Marco Island are the best known of the Ten Thousand Islands (Leighty et al, 1954).

Geologically the Big Cypress Swamp is characterized by Tamiami limestone of Miocene age. The limestone is rather impervious, containing much quartz sand of the Pamlico and Anastasia formations. The swamp is scalloped by many basins and cut by sloughs (Craighead, 1971). The Tamiami formation consists of the thin Tamiami Limestone, less than 150 feet thick (Parker, et al, 1955), and a thick section of greenish and greenish-grey argillaceous marls and silty, sandy, calcareous, shell marls and sands (Puri, 1964).

Soil of the Big Cypress Swamp is often pure sand, marl or mixtures of both which layer from 5 to 61 centimeters (2 to 24 inches) deep on the irregular surface of the limestone. Peat muck of various kinds fills the depressions in the bedrock. A thin layer of marl or sand is usually found just under the prairies and dwarf cypress. These soils deepen near the mangroves (Craighead, 1971). Approximately 20.3 percent of Collier County consists of Ochopee fine sandy marl, shallow phase (Leighty et al., 1954). The limestone is generally found from 15 to 30 centimeters below the surface. Cypress swamp lands account for approximately 18.6 percent of the Big Cypress Swamp and contain a variety of soils consisting of an intermingling of black or dark-grey mucky fine sand or peaty muck and brown peat with a subsoil of grey or light-grey fine sand. Thirty-two soil types are found in the Big Cypress Swamp and the southwest coast and Ten Thousand Islands.

The Big Cypress Swamp is unique in that nearly all surface waters originate within the Swamp from rainfall. There are no significant surface streams or rivers which flow into the swamp.

According to the U. S. Geological Survey (Klein et al., 1970) the Big Cypress Swamp can be divided into three sub-areas each having reasonable distinct internal drainage boundaries which are determined largely by topographic configuration and man-made drainage (Figure V-4). Sub-area A is northeast of a low ridge and drains southeastward into the Everglades and Conservation Area 3 of the Central and Southern Florida Flood Control District.

Sub-area B is located in the western portion of the Swamp. The historic sheet flow has been altered by an extensive system of canals that drain the water southward to Fahka Union Bay and Rookery Bay and westward to Naples Bay. This sub-area contains the most extensive residential development in the Swamp.

Sub-area C occupies the central portion of the Big Cypress Swamp. With the exception of the Turner River Canal, Barron River Canal and the easternmost GAC Canals the area has been changed very little by man. Fahkahatchee Strand, Okaloacoochee Slough, and Deep Lake Strand are the most well known natural features of this sub-area. Sheet flow exists in a large portion of sub-area C but the natural drainage is yielding to encroaching development along U. S. 41 and S. R. 84. Figure V-4 presents a generalized flow pattern for the Big Cypress Swamp during a relatively high flow period from November 18-20, 1969.

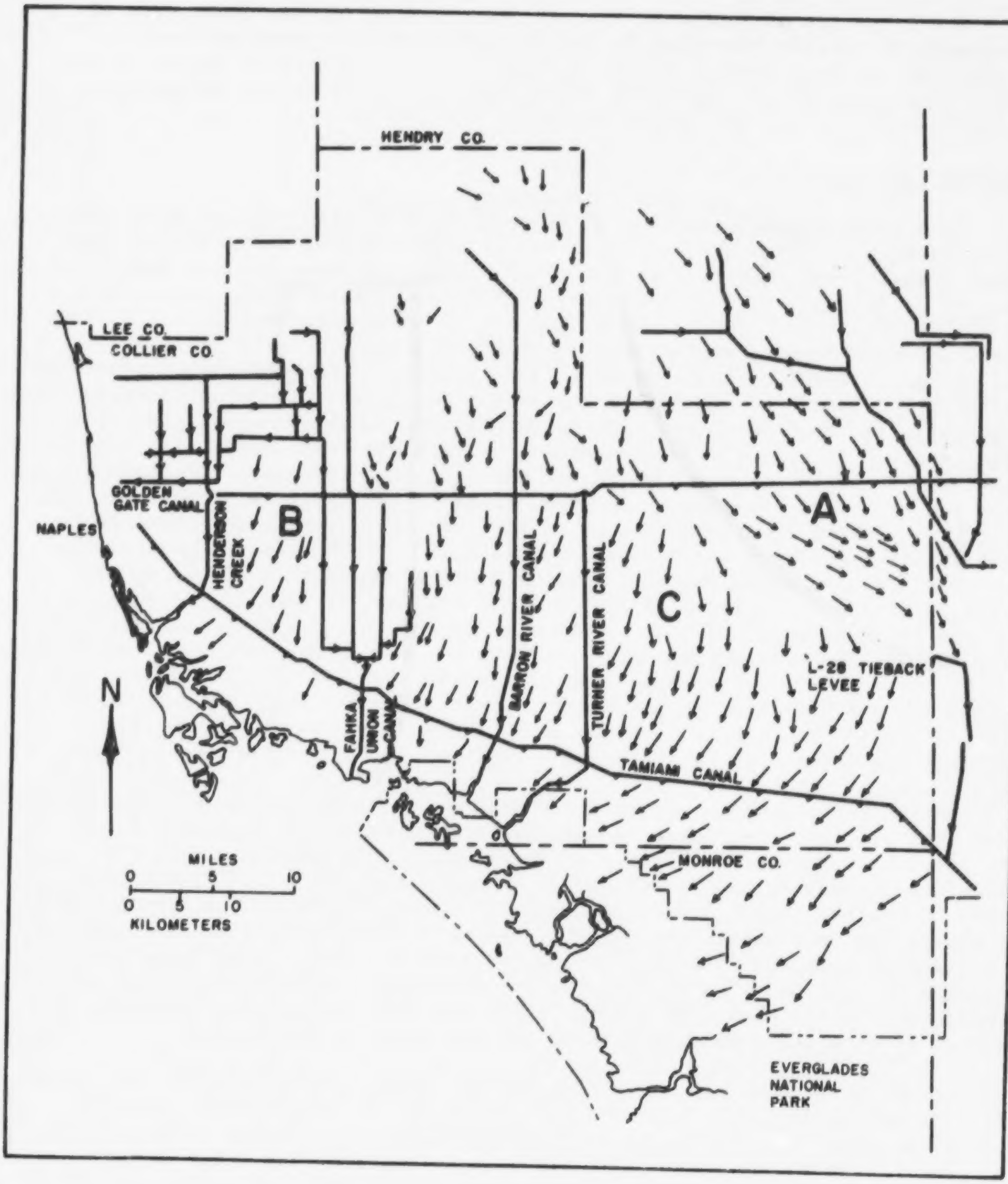

HENDRY CO.
LEE CO.
COLLIER CO.
GOLDEN GATE CANAL
NAPLES
HENDERSON CREEK
B
A
C
FAHKA UNION CANAL
BARRON RIVER CANAL
TURNER RIVER CANAL
L-28 TIEBACK LEVEE
TAMIAMI CANAL
MONROE CO.
N
MILES
0 5 10
0 5 10
KILOMETERS
EVERGLADES NATIONAL PARK

Figure V-4. The three distinct sub-areas of the Big Cypress Swamp showing major drainage patterns.

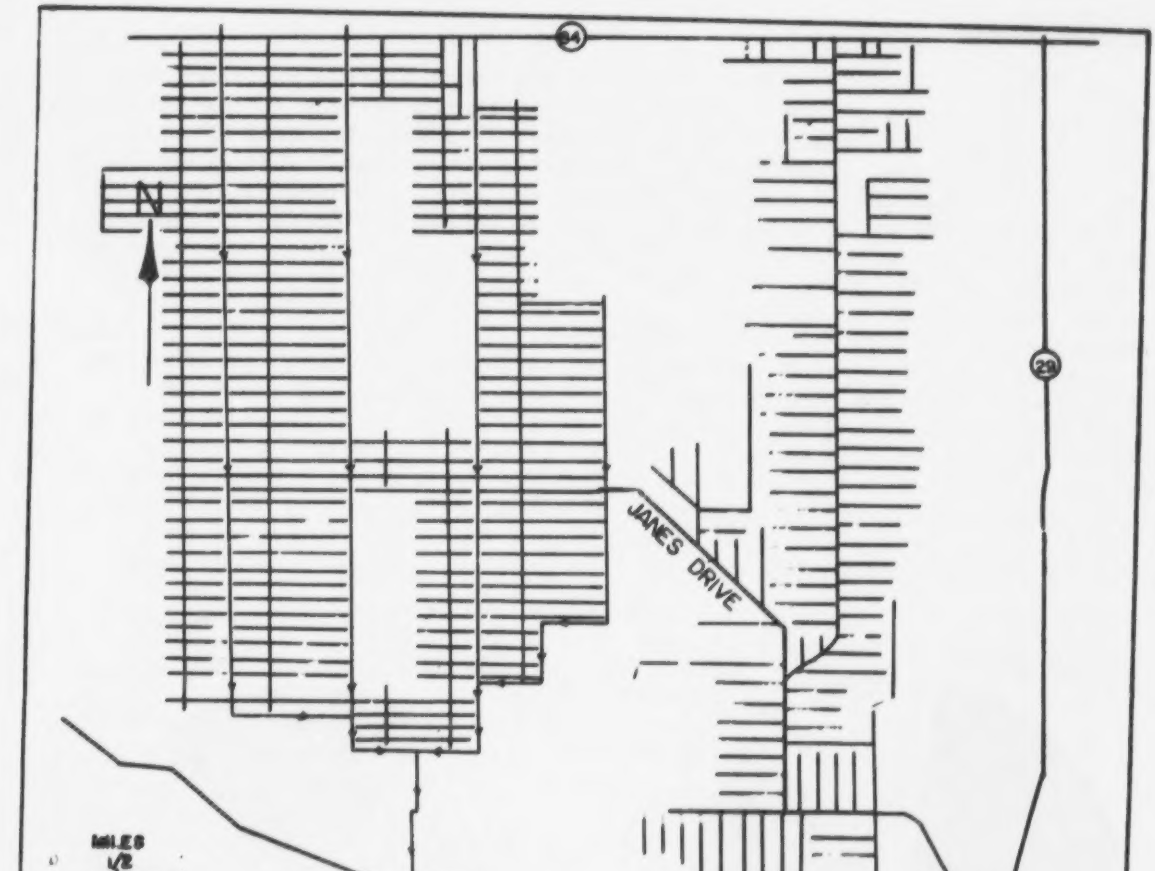
The estuaries of Southwest Florida are a complex system consisting of thousands of islands connected by intermingling tidal streams and passes. Salinities in these shallow estuaries depend on the freshwater input and may range from hypersaline conditions during the dry winter season to very low salinities during the wet summer season.

FAHKAHATCHEE STRAND

This study was focused on a small portion of the Big Cypress Swamp known as Fahkahatchee Strand and contiguous areas that included salt marshes, mangrove forests, and estuaries to the south. The study area was bounded to the east by S. R. 29, and on the north by S. R. 84 (Alligator Alley); on the west by the GAC drainage network, and by the Gulf of Mexico to the south. In total, the study area covered approximately 460 square kilometers (177.5 sq mi). Its unique native stand of Royal Palms is a well-known feature of the Fahkahatchee Strand. The Strand is also widely known for its spectacular orchid populations, especially in the deepest central slough. A more detailed map of the study area is given in Figure V-5. Inspection of this map indicates that the Fahkahatchee Strand is by no means an "undisturbed" ecosystem. Overland flow from the Okaloacoochee Slough and other areas to the north is effectively cut off by the system of highway borrow canals and GAC Properties drainage works that together surround the Strand on three sides. This effect is especially noticeable during storm periods, when waters that would normally be widely distributed and flow slowly toward the Gulf are rapidly transferred to the estuary by these canal systems. Virtually all of the virgin cypress was cut from the Fahkahatchee during logging operations that ended in 1950 (Craighead, 1971). Altogether, about 85 percent of the lands in Collier County are woodlands, and most have been subject to logging operations: of the virgin pine forest of the area, only 10 percent remained in 1954; the rest of the original pinelands were second growth stands of small size (Leighty, 1954).

In the Fahkahatchee, maple, willow and other swamp hardwoods have moved from their secondary position in the virgin forest to full dominance today. The logging operations involved the construction of a railway across the Strand that today forms the roadbed for Janes Scenic Drive. Approximately every 500 meters (1,600 ft) a perpendicular tramway built to facilitate removal of the felled logs enters the swamp; these were constructed so that no point in the swamp is more than 250 meters (800 ft) from dry land. This network of tramways is what provides the herringbone appearance of the Strand in Figure V-5. Immediately to the west, the platted roads and drainage ditches of Golden Gate Estates are nearing completion; these too are shown in Figure V-5.

Given these restrictions, we elected to concentrate on studies that might identify and explore the basic driving forces of the system; the resultant ecosystem metabolism and tuning to seasonal variation in these driving forces; and some of the possible dependencies among subsystems that might be producing integrated responses across the entire ecosystem from the upland forest to the estuary. We made comparisons of similar subsystems according to their location vis-à-vis the western boundary drainage works. Within the estuary, we examined mangrove fringed bays being fed directly from upland drainage works (Fahka Union Bay) and a bay somewhat removed from drainage inputs of fresh water (Fahkahatchee Bay) (Figure V-5). By organizing these efforts around compartmental models of ecosystem dynamics and energetics developed by H. T. Odum (1972), we tried to format our studies so as to be able to draw some tentative but general conslusions concerning ecosystem functioning and responses to drainage.


84
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JANES DRIVE
MILES
1/2
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KILOMETERS
COPELAND
FAHKA-UNION CANAL
BIG CYPRESS BEND
41
FAHKAHATCHEE BAY
CARNESTOWN
EVERGLADES CITY
CHOKOLOSKEE BAY
THOUSAND ISLANDS

Figure V-5. Map of study area and drainage works immediately to the west.

ECOSYSTEM MODELS

Early in the study period allocated to the South Florida Environmental Study, the Department of the Interior (NPS) contracted a group at the University of Florida Center for Aquatic Science to construct a set of models of the south Florida regional ecosystem and some of its subsystems. That study (Lugo et al., 1971) attempted to coalesce previous environmental studies done within the region, and the views of individuals active in south Florida environmental fields, into an overview of environmental processes and interactions important to the south Florida basin. In order to use that study as an organizational tool, we needed first to define the ecosystem types present within the Fahkahatchee study area and in the Big Cypress as a whole. We used a published map series on soil types and associated native vegetation (Leighty, 1954) for this purpose. By polar planimetry of these maps we determined the areal distribution of plant community types within the study area, which results are given in Figure V-6a. To compare the study area to the whole Big Cypress complex, we planimetered that portion of the Big Cypress lying within Collier County; plus the salt marsh, mangrove, and estuarine areas from Naples south to the Collier - Monroe County line (see Figure V-3). The result of this procedure is presented in Figure V-6b. The greater representation of deep slough communities (swamp hardwoods and cypress) in the study area (Figure V-6a). is due to centering on the Fahkahatchee slough; and the lesser representation of mangrove and estuary in the overall pattern (Figure V-6b) is caused by two factors: (1) the larger inland area involved, and (2) cut-off of estuarine

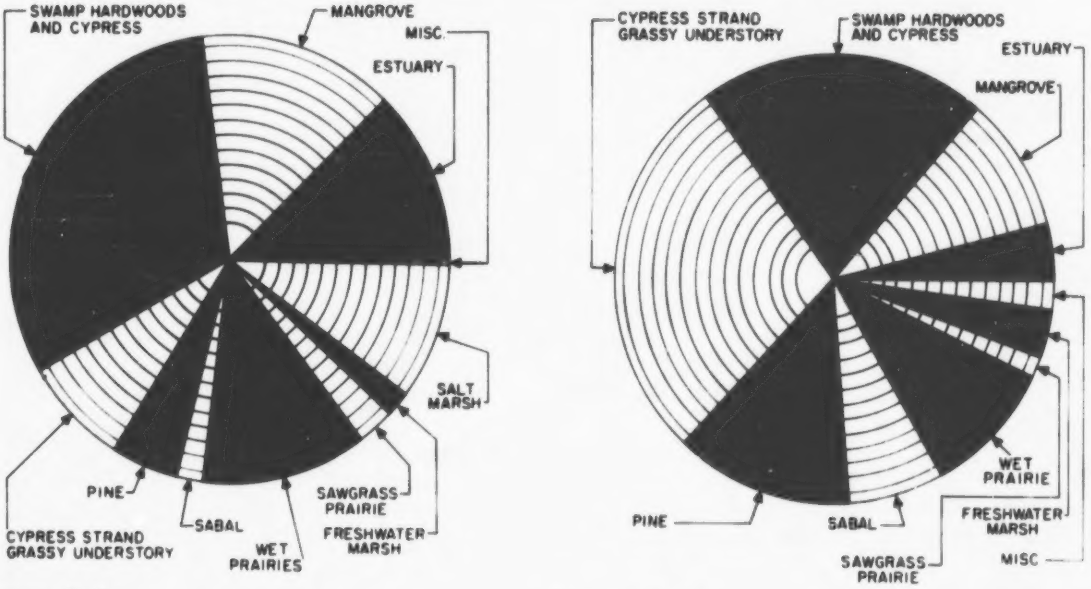


Figure V-6a.

Figure V-6b.

Proportional representation of the distribution of plant community types in the Fahkahatchee Strand study area (6a) and that portion of the Big Cypress Swamp and its associated estuary lying within Collier County, Florida (6b). The Fahkahatchee area is included as part of the total Big Cypress analysis.

areas connected to the Big Cypress that lie in Monroe County. Nonetheless the community types of both areas are the same, and these acreages might be used with estimates of productivity for the various subsystems to estimate the total organic energy budget of the region.

Our criteria for determining the effort to be expended on any given site type were based on several factors. The first was importance of each subsystem to the overall region, indicated by its areal representation. Secondly, we hoped to delineate the influence of artificial drainage on each subsystem by pairing sites strongly influenced by drainage with sites relatively remote from the canals. In effect, we hoped to choose sites that would simulate an experimental approach to drainage effects by studying similar communities that differed simply in location vis-à-vis existing drainage works.

A subset of the original set of ecosystem models formulated by Lugo, et al. (1971) can be found in Appendix B with the material they produced to describe the models. That appendix is an abstraction from their report of subsystem models appropriate to the Big Cypress area. For our purposes, these models required considerable simplification to make them amenable to a field investigation period of one calendar year using limited manpower. In addition, our models were intended as hypotheses of system function that could ultimately be used for computer simulation, and large models designed to serve as diagrams for organizing and coordinating research are unwieldy in that context. Several revisions of our models were also made necessary as field work and analytical limitations became apparent during the course of the study period.

VI - CLIMATOLOGY

INTRODUCTION

The subtropical climate in south Florida is directly responsible for many of the biological and physical features of the Big Cypress Swamp and the Everglades. This subtropical climate with its alternate wet and dry seasons, is generally favorable to the phenomenal plant growth of the area. The high relative humidity found in various swamps is at least indirectly responsible for many of the native orchids which are found in no other location throughout the world. Severe natural disturbances to the ecosystem occur only when the normal climatic extremes are exceeded during excessive droughts and freezes, and during hurricanes.

Some of the unique biological adjustments resulting from the climate and the edaphic factors of south Florida are seen in the mangrove forests that flourish under alternate baths of fresh and salt water; in the tropical hardwood hammocks that provide a mild microclimate of high humidity and frost-free temperatures suitable to a tropical flora of trees, ferns, orchids, and bromeliads, and in the pineland forests of the rock land that support more than 100 endemic plants adapted to the fires of the dry period (Craighead, 1971).

RAINFALL

Methods

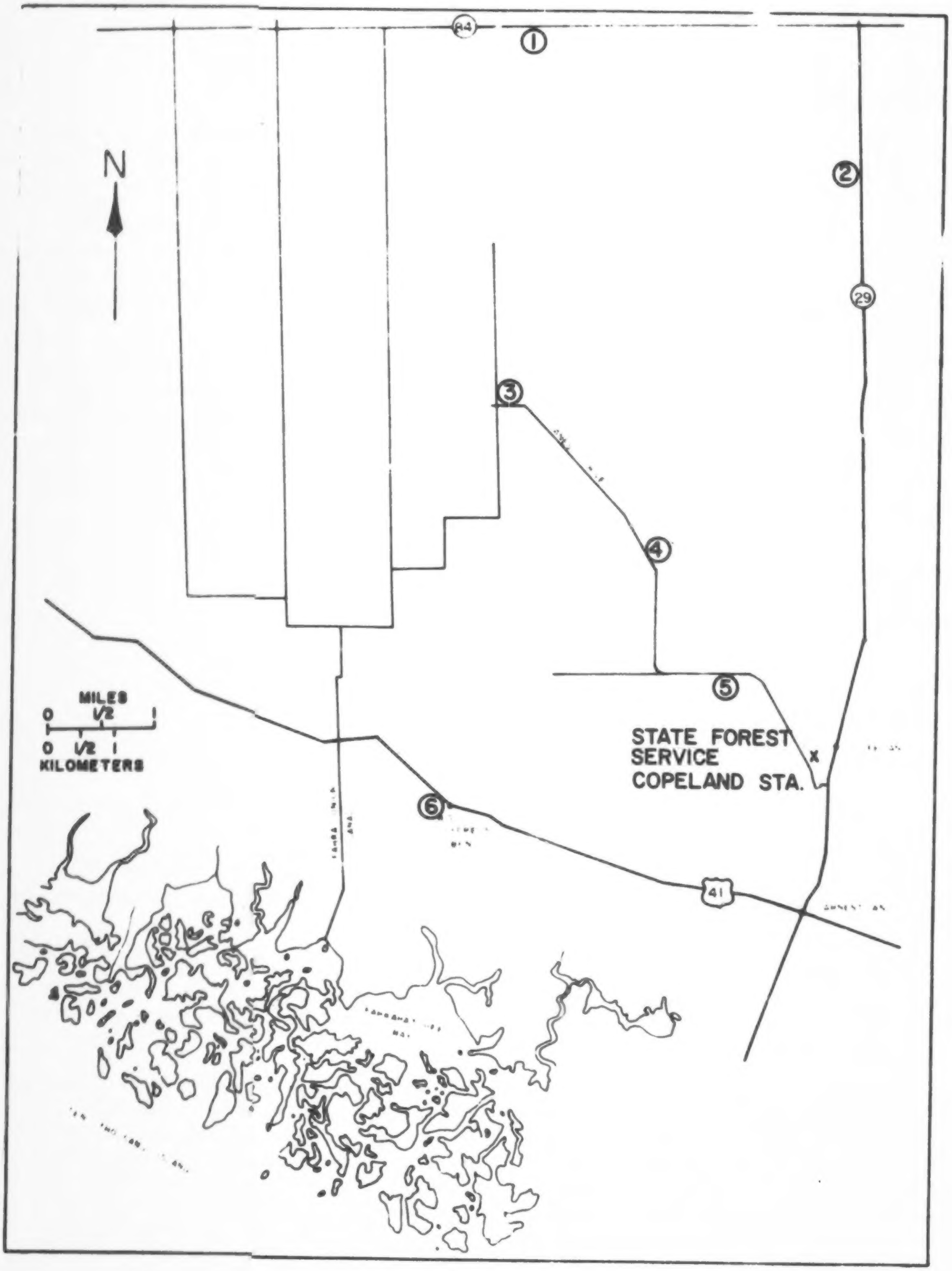
Six Universal Weighing Rain Gages were strategically located in the study area (Figure VI-1). The rain gages were designed to receive a maximum of 30.5 centimeters (12 inches) of rainfall with a 196 hour recorder.

Background

Highly variable temporal and spatial rainfall patterns are well documented for south Florida. A striking example occurred in 1947 when 298.7 centimeters (117.6 inches) of rain fell east of the southern portion of Water Conservation Area No. 1, while only 105 kilometers (65 miles) to the northeast some 142.2 centimeters (56.0 inches) of rainfall occurred over Taylor Creek (Department of the Army, January 15, 1968).

The hydroperiod of southwest Florida is historically defined. Generally 60-65 percent of the annual precipitation occurs during the summer months of June through August. The winter months of December through February account for some 8-10 percent of the rainfall.

During the winter and early spring, frontal movements result in widespread light-to-moderate rains in south Florida which may last two or three days. From late spring to autumn, easterly warm, moist air masses move inland from the Atlantic Ocean and the Straits of Florida. Low pressure areas over the Atlantic Ocean and Gulf of Mexico also provide large quantities of moisture inland. Prolonged periods of precipitation can result from continued inland air-flow around slow moving pressure centers. Sea breezes contribute to the moisture supply in a relatively narrow band along the coast. Much of the summer rainfall occurs in the form of thunderstorms, and varies greatly in intensity and locality. Winter thunderstorms are usually a closely spaced


N
84
①
②
29
③
④
⑤
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X

Figure VI-1. Map of study area showing climatology station locations.

series of cells in an extended squall line or in locally unstable air, and rarely occur in any great number. Summer frequency of thunderstorms can be as high as 60 percent. Hurricanes and less severe tropical storms are at times major sources of precipitation (Department of the Army, January 15, 1968).

Several excellent reports have been prepared concerning analysis of rainfall frequency for southern Florida. Of concern to the study area Hughes, et al., (1971) reports the following rainfall based on the period 1931-1955: annual 132-142 centimeters (52-56 inches); winter 13 centimeters (5 inches) spring 20-25 centimeters (8-10 inches); summer 61 centimeters (24 inches); and autumn 36-41 centimeters (14-16 inches). Thomas (1970) reports rainfall on an annual monthly basis (Table VI-1).

Table VI -1. Annual and monthly mean rainfall in the vicinity of Fahkahatchee Strand based on analysis of historical rainfall by T. M. Thomas.

	Rainfall	
Month	Centimeters	Inches
Jan.	2.5- 5.1	1-2
Feb.	2.5- 5.1	1-2
Mar.	2.5- 5.1	1-2
Apr.	5.1- 7.6	2-3
May	10.2-19.3	4-5
June	20.3-22.9	8-9
July	20.3-22.9	8-9
Aug.	17.8-20.3	7-8
Sept.	22.9-25.4	9-10
Oct.	10.2-15.2	4-6
Nov.	2.5- 5.1	1-2
Dec.	2.5- 5.1	1-2
Annual	127 - 152	50-60

The National Weather Service maintains two long term weather stations in the vicinity of Fahkahatchee Strand. One is located in Everglades City, Florida, and the other in Naples, Florida. Extreme variations in annual rainfall are noted at both sites (Figures VI-2 and 3). Everglades City experienced a maximum annual rainfall of 198.6 centimeters (78.19 in) during 1948 and a minimum of 92.7 centimeters (36.50 in) in 1942. The average annual rainfall at Everglades City based on the period 1931-1972 is 138.2 centimeters (54.41 in). Rainfall for 1972 was 157.1 centimeters (61.85 in) some 14 percent above normal. Maximum rainfall at Naples occurred in 1959 with 184.2 centimeters (72.50 in) and a minimum in 1944 with 77.7 centimeters (30.60 in). Average annual rainfall for the period of record 1941-1972 is 133.73 centimeters (52.65 in). Naples received 141.7 centimeters (55.78 in) during 1972, some six percent above normal.

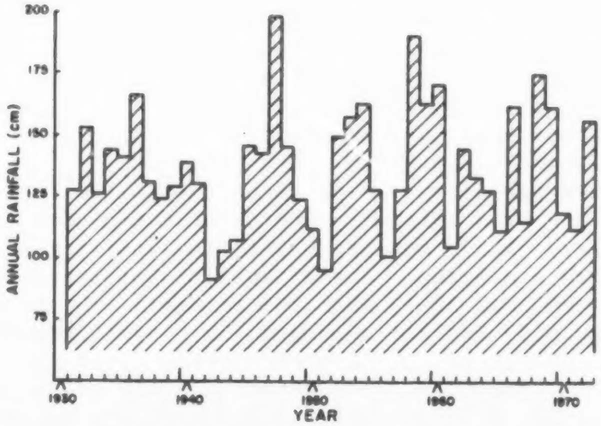


Figure VI-2. Annual rainfall at Everglades City, Florida, 1931-1972.

Monthly rainfalls are more dynamic than annual rainfalls. As observed from Figure VI-4 seven months have records of zero precipitation at Everglades City. The most variable month is June, when historic rainfalls have ranged from a low of 6.45 centimeters (2.54 in) to a high of 62.8 centimeters (24.73 in) with a mean of 24.51 centimeters (9.65 in). Monthly rainfall of less than 2.54 centimeters

(1 in) occurs 55 percent of the time for January and 45 percent for November. The rainfall may be expected to exceed 25.4 centimeters (10 in) 44 percent of the time for June and 26 percent of the time for July.

Figure VI-5 is a summary of annual and monthly rainfall at Naples for the period May, 1940-December, 1972. As expected, the rainfall pattern at Naples was different from Everglades City. For example, the month with the maximum and highest average rainfall was September, however, it is obvious that the same hydroperiod is definable from either set of records.

During 1972 both communities received above average rainfall (Figure VI-6). The greatest positive departure from the average monthly precipitation at both locations was during June due to the effects of Hurricane Agnes. Seven months produced positive departures while five were negative.

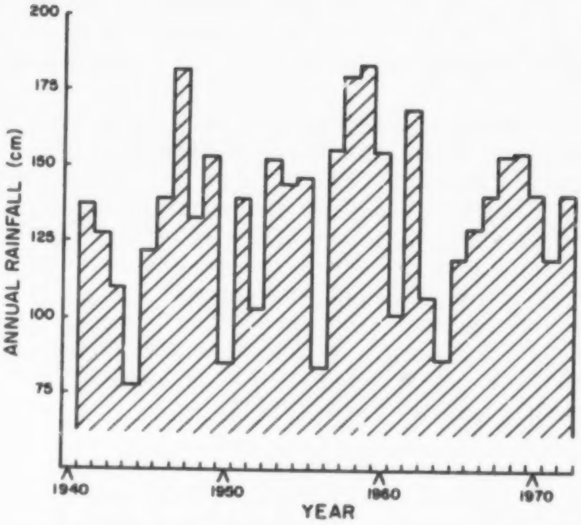


Figure VI-3. Annual rainfall at Naples, Florida, 1941-1972.

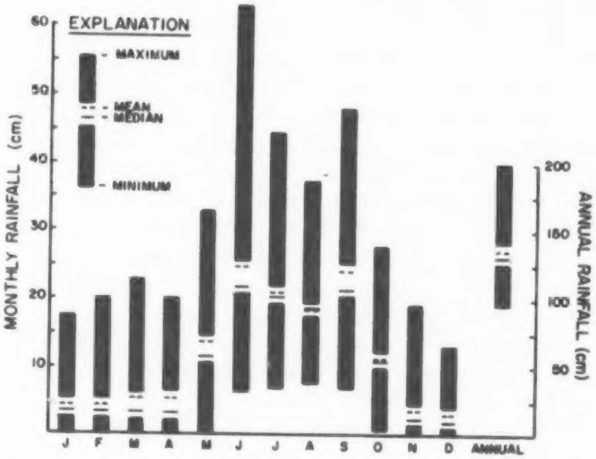


Figure VI-4. Summary of annual and monthly rainfall at Everglades City, Florida, 1931-1972.

Results

Rainfall (Figures VI-7 and 8) within the Fahkahatchee Strand study area for 1972 varied from a low of 120.13 centimeters (47.30 in) near the middle of Janes Scenic Drive (Station 4) to a high of 194.03 centimeters (76.39 in) at the State Forest Service Tower near the eastern side of Janes Scenic Drive. The yearly average of the seven sites was 141.64 centimeters (55.74 in). Compared with long term rainfall records at Everglades City only two of the seven stations were "above average", yet, the yearly mean was 3.41 centimeters (1.35 in) above average. The effects of Hurricane Agnes were obvious over the period from June 16-19 when the rainfall ranged from 14.2 to 16.7 centimeters (5.61 to 6.59 in) and averaged 152.2 centimeters (5.98 in).

Based on the average rainfall of 141.64 centimeters during 1972, a total of 650,877,000 cubic meters (527,672 ac-ft) of water fell on the study area during the year. Of this, some 409,929,000 cubic meters (332,359 ac-ft) arrived north of U. S. 41 and 240,958,000 cubic meters (195,313 ac-ft) south of U. S. 41.

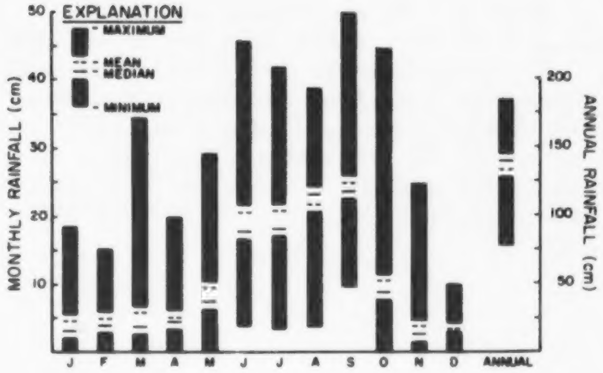


Figure VI-5. Summary of annual and monthly rainfall at Naples, Florida, 1940-1972.

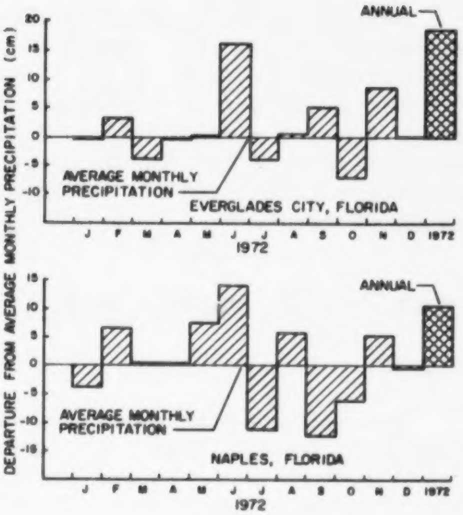


Figure VI-6. Departure from average monthly rainfall at Everglades City and Naples, Florida during 1972.

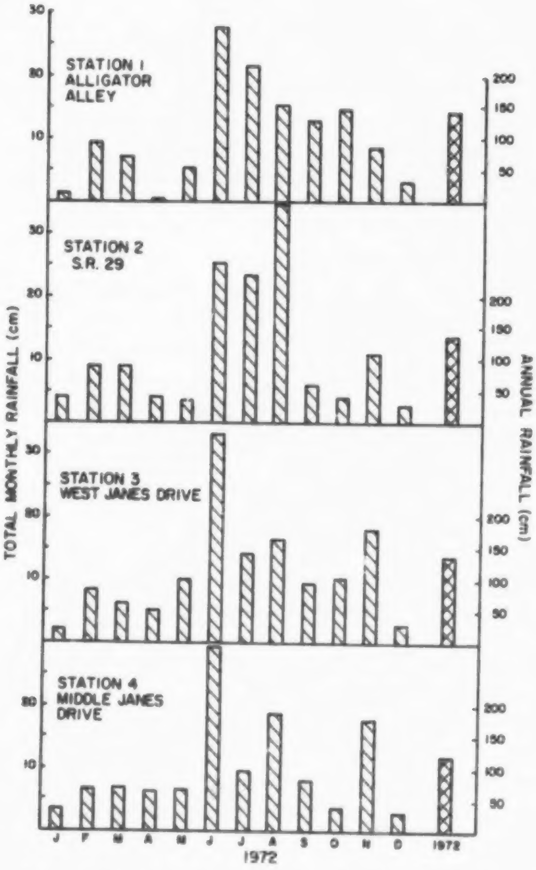


Figure VI-7. Rainfall during 1972 at four sites in Fahkahatchee Strand.

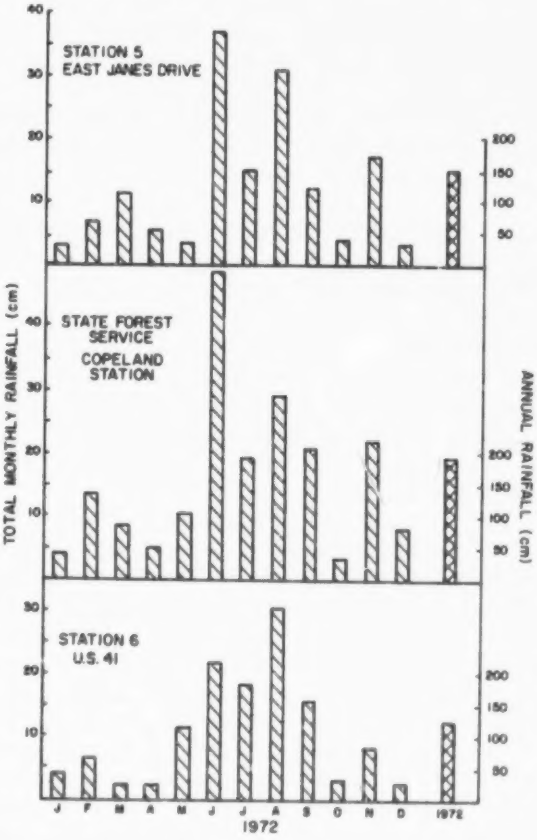


Figure VI-8. Rainfall during 1972 at three sites in Fahkahatchee Strand.

Maximum daily rainfall occurred on June 18 with an average of 11.75 centimeters (4.63 in). Rainfall exceeded 2.54 centimeters (1.0 in) on 45 days, 5.08 centimeters (2.0 in) on 10 days, 7.62 centimeters (3.0 in) on 3 days and 10.6 centimeters (4.0 in) on one day at various locations throughout the study area. Seventy percent of the daily rain observations were less than 1.77 centimeters (0.5 in) and 29 percent less than 0.25 centimeter (0.1 in). Rainfall was recorded on 168 days during 1972. Because of the spatial distribution of rainfall, it was common to observe rain at only one of the six EPA stations on any given day.

TEMPERATURE AND RELATIVE HUMIDITY

Methods

Two Belfort Instrument Company Hygrothermographs were installed in Falkenberg Company Instrument Shelters at Station 2 located at the County Prison Farm on S. R. 29 and Station 6 at Big Cypress Bend (Figure VI-1). Each instrument was calibrated weekly with a standard thermometer and sling psychrometer.

Background

Throughout south Florida temperatures are moderately high from July through September and pleasantly warm to cool from October through May. Because of temperature effects of the Gulf of Mexico, coastal areas are cooler than inland areas during the summer and warmer in the winter. Frost generally occurs yearly in the Big Cypress Swamp, but rarely in the Ten Thousand Islands and other coastal areas. With few exceptions relative humidity is moderate to high in south Florida.

The National Weather Service maintains two weather stations near the study area: one at Everglades City, Florida, and one at Naples, Florida. The average temperature (1931-1972) at Everglades City (Figure VI-9) is 23.8° C with extremes ranging from minus 4.4° C to 37.2° C. Temperatures at Naples have averaged 0.2° C cooler than Everglades City (Table VI-2) based on the period of record. As observed from Table VI-2 the temperature for January 1972 was 3.3° C above average. Seven of the twelve months during 1972 were above average.

Results

Weekly ranges in temperatures for Stations 2 and 6 are presented in Figures VI-10 and 11. Yearly temperature range at Station 6 was 4.4° C to 35.6° C with an average of 23.0° C.

Table VI-3 presents the 1972 average monthly temperatures for Stations 2 and 6. Since the nearest long term weather station at Everglades City is located some 20.4 kilometers (12.7 mi) south of Station 2 and 9.6 kilometers (6 mi) southeast of Station 6, it would be inappropriate to infer numerical deviations from the long term trend. However, it can be concluded that based on the long term records from Everglades City and Naples that the months of January, February, March, October, November, and December were above the long term mean.

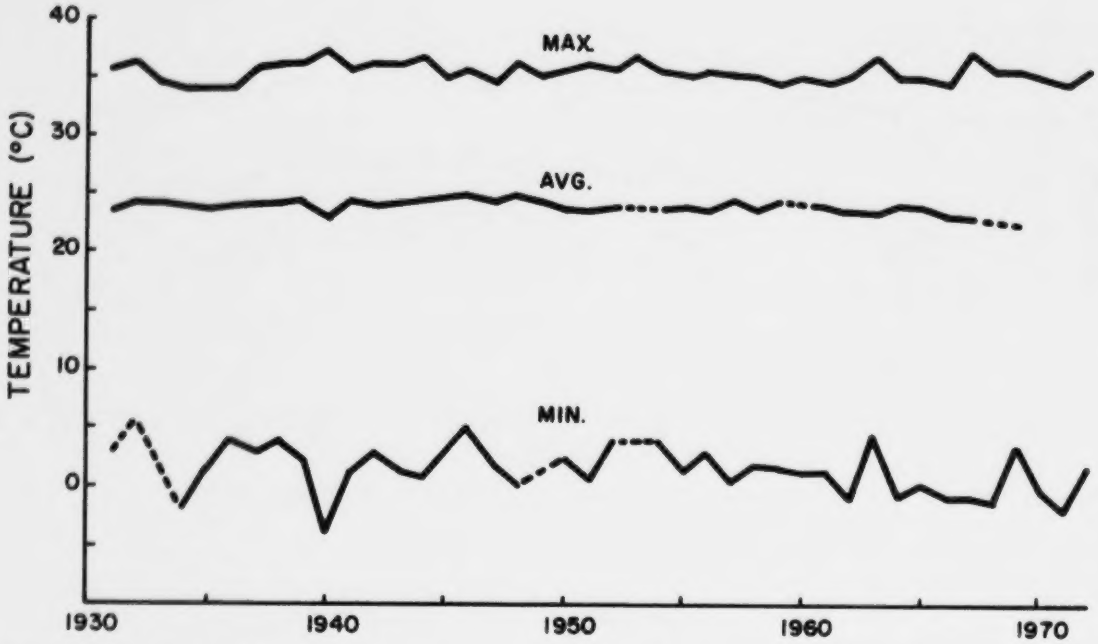


Figure VI-9. Yearly temperature range at Everglades City, Florida, 1931-1972.

Table VI-2. Average monthly temperature (° C) for Everglades City and Naples, Florida.

Month	Naples		Everglades City	
	1941-1972	1972	1931-1972	1972
January	18.5	21.8	18.9	20.9
February	18.8	19.3	19.3	18.0
March	20.7	21.2	20.9	*
April	23.1	23.1	23.2	22.3
May	25.1	25.3	25.2	24.9
June	27.2	26.6	27.0	26.2
July	28.0	27.6	27.9	*
August	28.3	27.8	28.1	*
September	27.7	27.6	27.7	27.7
October	24.8	25.4	25.4	*
November	21.7	22.7	22.0	23.2
December	19.3	20.7	19.5	20.4
Average	23.6	24.1	23.8	*

* Unavailable

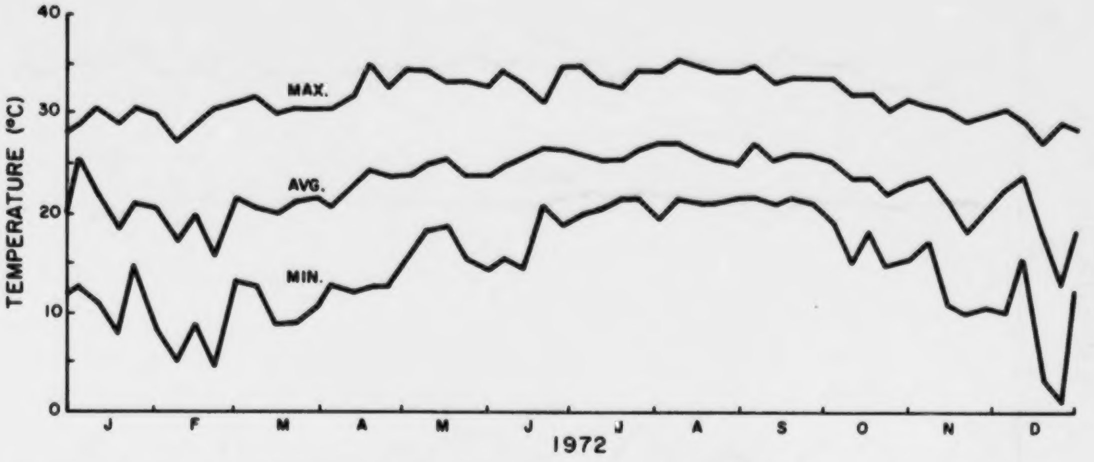


Figure VI-10. Weekly temperature range at Station 2 during 1972.

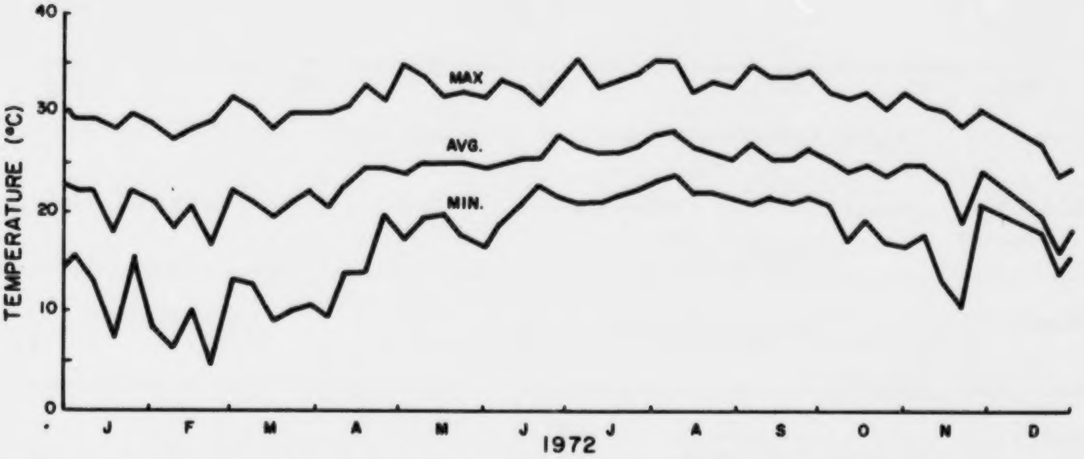


Figure VI-11. Weekly temperature range at Station 6 during 1972.

As expected, relative humidity remained moderate to high at both Station 2 and 6 throughout the year (Figures VI-12 and 13). Maximum daily relative humidity usually occurred in the late afternoon until mid-morning, and was often close to 100 percent. Daily minimums occurred during the early afternoon when temperatures were at a maximum. Average yearly relative humidity at Station 2 was 88.6 percent with a range of 24-100 percent. At Station 6 the average was 87.3 percent with a range of 30-100 percent. Table VI-4 presents the average monthly relative humidity at both sites for 1972.

SOLAR ENERGY AND PAN EVAPORATION

Methods

Total solar radiation was measured throughout the study period with a Belfort Instrument Company Pyrheliograph atop a standard instrument shelter at Station 6 (Big Cypress Bend). Charts were read weekly and the total solar radiation reported daily.

Pan evaporation was measured at Station 2 and Station 6. A standard 1.83 meter (6 ft) diameter stainless steel evaporation pan was used in conjunction with a Stevens Type F recorder for direct measurement of evaporation. To minimize line shift errors and float lag, a 41 centimeter (16 in) diameter copper float with a beaded float line was used. A 46 centimeter (18 in) stilling well negated the effect of wind action on the float.

Table VI -3. Average monthly temperatures at Stations 2 and 6 for 1972.

Month	Temperature (° C) Station 2	Temperature (° C) Station 6
Jan.	20.4	21.0
Feb.	20.0	20.6
Mar.	21.0	21.2
Apr.	22.7	22.7
May	24.7	24.8
June	25.6	26.0
July	26.1	26.3
Aug.	26.2	26.8
Sept.	26.1	26.4
Oct.	23.8	24.5
Nov.	21.1	22.6
Dec.	18.7	19.1

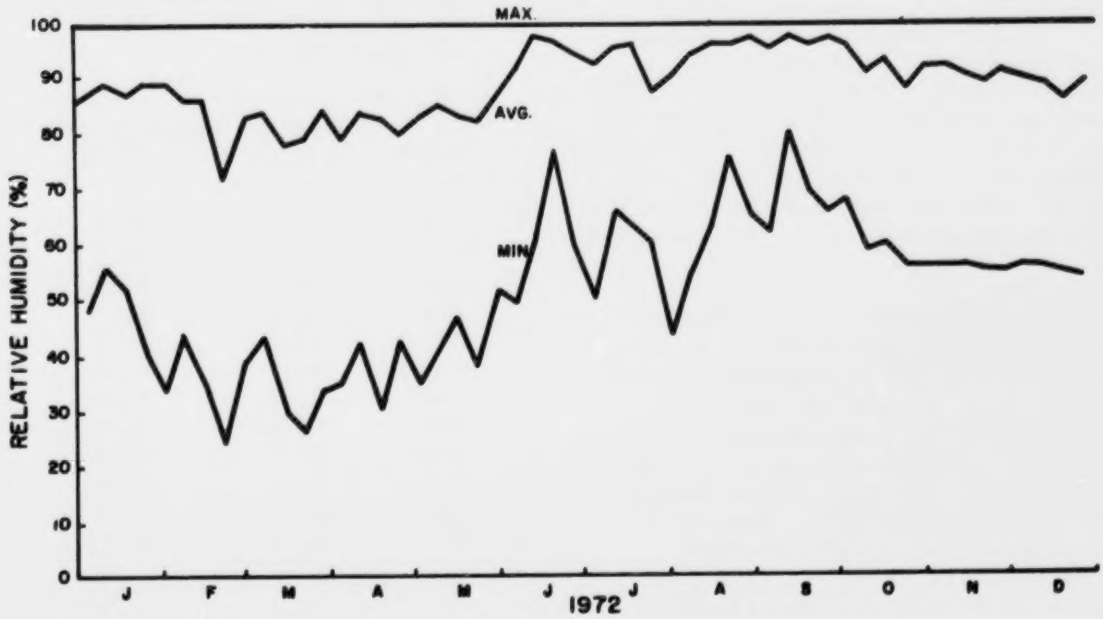


Figure VI-12. Weekly relative humidity range at Station 2 during 1972.

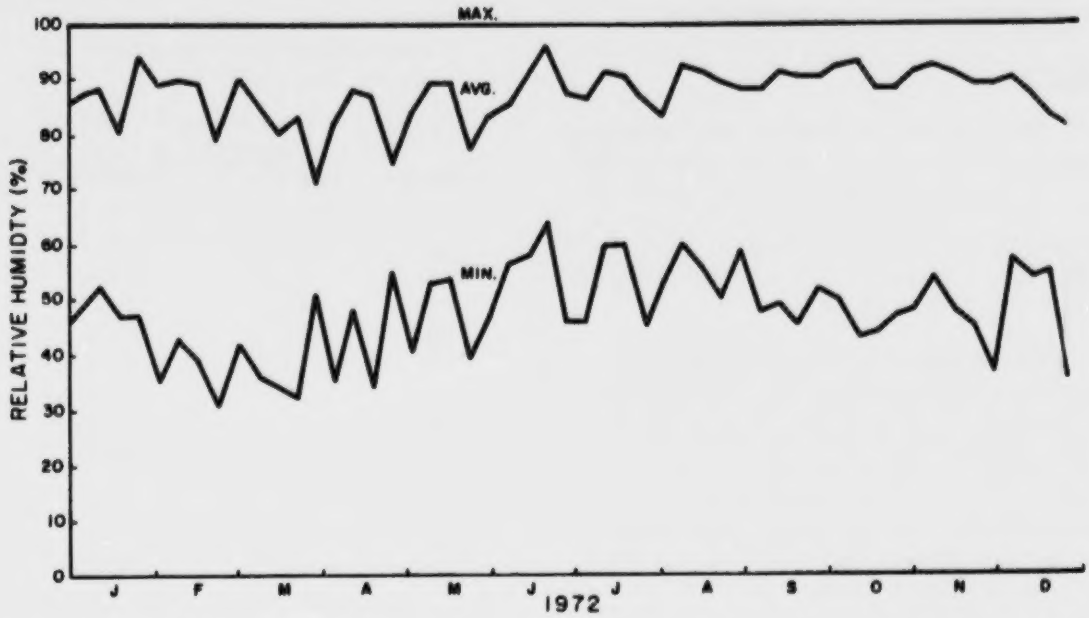


Figure VI-13. Weekly relative humidity range at Station 6 during 1972.

Results

Weekly ranges of solar energy are presented in Figure VI-14. A maximum daily solar radiation of 745 langleys/day occurred during the week of July 9. The maximum average weekly solar radiation occurred June 24-31 at 620 langleys/day and the minimum during December 16-23 at 270 langleys/day.

Total yearly pan evaporation (Figure VI-15) varied from 124 centimeters (48.7 in) at Station 2 to 155 centimeters (61 in) at Station 6. Maximum monthly evaporation at both stations occurred during April and May and minimum evaporation during November and December. Station 6 is located at Big Cypress Bend approximately 98 meters (100 yards) south of U. S. 41. The site is in the open and there are no immediate trees to provide relief from the sun. Station 2, located some 49 meters (50 yards) west of S. R. 29 at the Florida Department of Transportation Prison, received partial shading during portions of the day. The difference in the two pan evaporation rates is probably the consequence of shading. Nevertheless, the average pan evaporation for the two sites was 24.06 centimeters greater than the average precipitation within Fahkahatchee Strand for the same period (1972).

Table VI -4. Average monthly relative humidity at Stations 2 and 6 for 1972.

Month	Relative humidity (%) Station 2	Station 6
Jan.	87.8	89.1
Feb.	82.7	85.5
Mar.	81.5	84.2
Apr.	81.8	84.2
May	83.3	85.5
June	94.4	90.0
July	92.7	88.0
Aug.	95.2	89.9
Sept.	96.0	89.5
Oct.	92.3	87.9
Nov.	90.7	91.2
Dec.	85.4	82.2

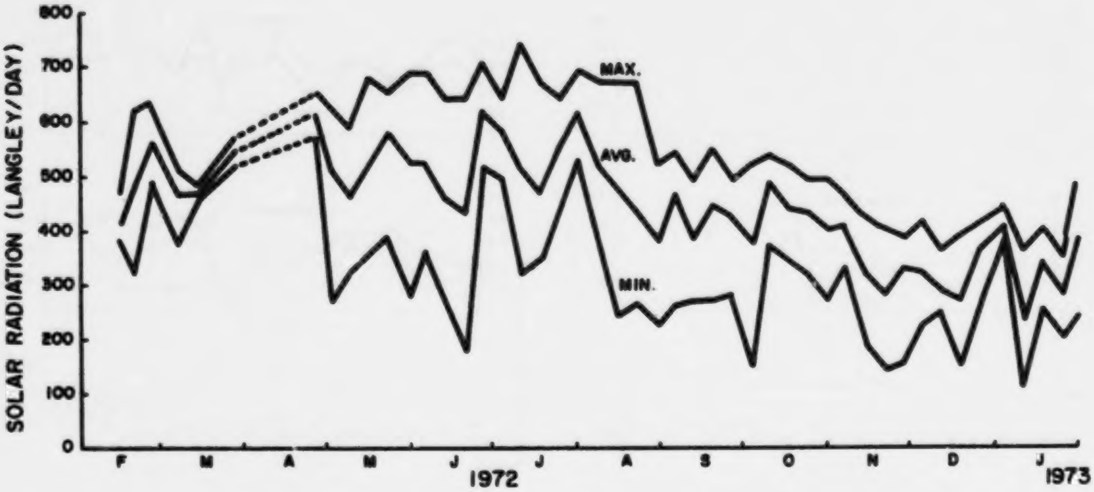


Figure VI-14. Weekly solar energy range at Station 6 during 1972.

Pan evaporation is directly related to solar energy, wind speed, temperature, and humidity. Figure VI-16 presents pan evaporation and solar energy versus time. As expected, pan evaporation varies directly with total solar energy. For the study area, pan evaporation may be approximated by the following equation based upon Figure VI-16:

$$\text{Pan evaporation (cm/day)} = (1.25 \times 10^{-3}) \text{ (Solar energy (langleys/day))}.$$

Refinements may be made to the above equation by applying wind speed, temperature and humidity factors. These complexities will be cultivated in the following discussion of evapotranspiration.

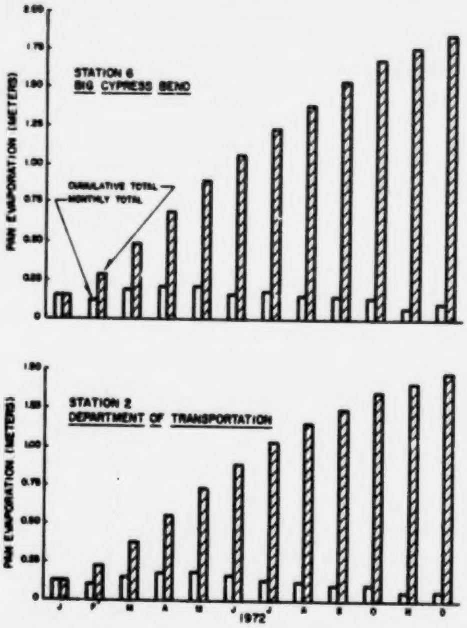


Figure VI-15. Monthly pan evaporation at Stations 2 and 6 during 1972.

EVAPOTRANSPIRATION

Water is seemingly abundant in south Florida, with large annual average rainfalls and ground water elevations near ground surface. However, expanding populations and agriculture are demanding fresh water at ever increasing rates. In order to ascertain the quantity of water any particular area can yield, several parameters must be resolved. Rainfall readily passes into the shallow water table in areas covered by sand, but in areas where the surface is covered by more impervious substances such as marls or limerock much of the rainfall is lost by runoff.

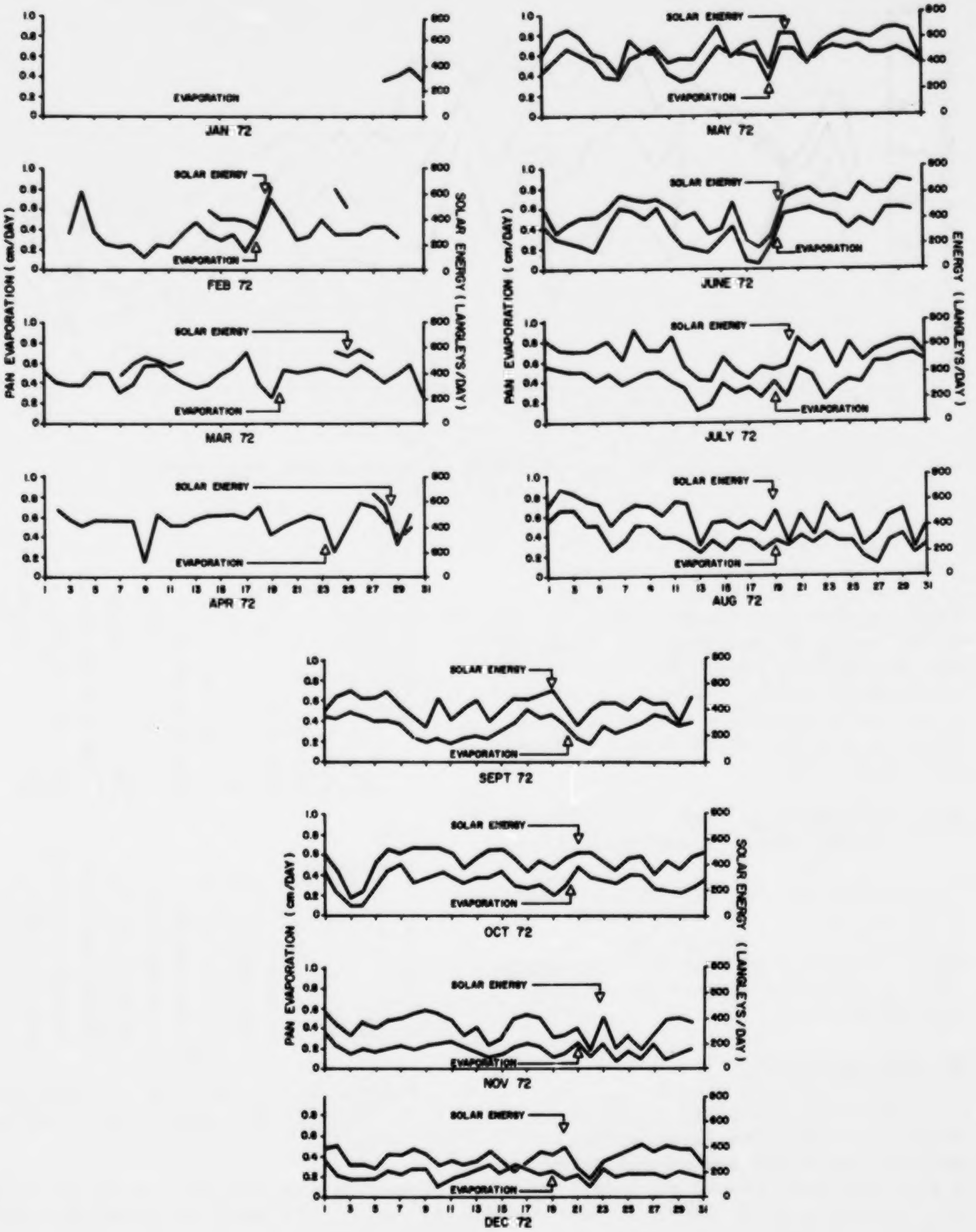


Figure VI-16. Solar energy and evaporation in Fahkahatchee Strand during 1972.

A portion of the rainfall which reaches the aquifer then meets demands from adjacent areas by hydraulic gradients to drainage canals. Another demand to the rainfall is evapotranspiration. This term has been coined to be the sum of evaporation and transpiration.

Evaporation is the movement of water back into the atmosphere from surface areas. These surface areas include open water, rock, vegetation and soil. When the ground water table is near the surface the evaporation from soil is greatly enhanced due to capillary rise of the water and is almost equal to evaporation from a free-water surface.

Transpiration is the return of water to the atmosphere by moving up through and out from plants. Thus, the sum of the terms become evapotranspiration, which may be interpreted as being the water moved back into the atmosphere from moistened surfaces and by movement through plant cells.

Theoretical Methods

Numerous studies have been conducted concerning evapotranspiration and its relation to climatic parameters and vegetation types. This report will compare several evapotranspiration estimating methods to field evapotranspiration measurements.

One of the most complete analysis was made by Penman (1948). His long and tedious formula for potential evapotranspiration is based upon several climatic parameters and is as follows:

$$E_t = \frac{\Delta H + 0.27\ E_a}{\Delta + 0.27}$$

with $H = R_A(1-r)(0.18+0.55\,{}^n/N) - \sigma T_a{}^4(0.56-0.092\sqrt{e_d})(0.10+0.90\,{}^n/N)$

and $E_a = 0.35(e_a - e_d)(1+0.0098\ U_2)$

where H = daily heat budget in mm H_2O/day

R_A = mean monthly terrestrial radiation in mm H_2O/day

r = reflection coefficient of the surface

n = duration of bright sunshine

N = maximum possible duration of bright sunshine

σ = Boltzman constant

T_a = mean monthly absolute temperature of the air (° C)

e_d = saturated vapor pressure at mean dew point in mm Hg

E_a = saturated vapor pressure at mean air temperature in mm Hg

U_2 = mean windspeed at 2 meters in miles/day

E_t = evapotranspiration in mm H_2O/day

Δ = slope of saturated vapor pressure curve of air at mean monthly temperature in mm Hg/^{o} F.

Penman's coefficients were determined for a rather humid area, not far from the ocean, covered with abundant growth. However, the method does not include rainfall data, but assumes that the ground is completely shaded by vegetation and never short of water.

Thornthwaite (1948) attempted to develop a simpler expression of potential evapotranspiration assuming ideal conditions of soil moisture and vegetation. He developed a monthly heat index related to monthly mean temperature and latitude. This index is then used to compute monthly evapotranspiration. Thornthwaite found that his computed potential evapotranspiration is an excellent index to stages of plant growth in that a given crop variety requires normally a certain amount of water.

Four experimental watersheds located in the southern Florida flatwoods were investigated (Stewart and Mills, 1948) in order to apportion runoff, seepage losses, evapotranspiration, changes in soil moisture and ground water storage from weather records on a watershed basis.

Stewart and Mills computed watershed evapotranspiration from the relationship of:

$$E_t = P - R \pm \Delta S$$

where P = precipitation

R = runoff

ΔS = change in storage.

Realizing that the maximum evapotranspiration is limited by solar radiation when soil moisture is not limiting, and that rainfall limits actual evapotranspiration since it limits soil moisture they then related evapotranspiration to pan evaporation and rainfall. From the four experimental watersheds the following equation was derived:

$$E_t = E_p(0.081+0.133P)$$

where E_t = evapotranspiration in inches/month

E_p = pan evaporation in inches/month

P = precipitation in inches/month.

Table VI-5 presents a comparison of monthly mean pan evaporation (2 sites) and precipitation (6 EPA sites) for Fahkahatchee Strand to computed potential evapotranspiration. The Penman method estimates the potential evapotranspiration to be 148.5 cm/yr or 89.08 percent of the pan evaporation. Thornthwaite and Stewart methods yielded quite similar yearly results.

Figure VI-17 is a graphical representation of the information given in Table VI-5. Stewart's method is shown to follow closely the monthly precipitation while Thornthwaite and Penman methods follow more generally the monthly pan evaporation.

Table VI-5. Computed evapotranspiration compared to pan evaporation and precipitation in Fahkahatchee Strand during 1972. (cm H_2O)

Month	Pan Evaporation	Precipitation	Penman Method	Thornthwaite Method	Stewart Method	Avg. of 3 Methods
Jan.	14.1	2.9	7.8	6.3	3.3	5.8
Feb.	11.5	7.7	7.9	4.4	5.5	5.9
Mar.	17.4	7.2	14.0	6.3	8.0	9.4
Apr.	19.0	4.1	14.9	9.0	5.6	9.8
May	19.6	6.6	17.1	11.3	8.4	12.3
June	15.9	29.0	15.5	12.8	25.6	18.0
July	16.0	16.8	17.4	13.9	15.4	15.6
Aug.	13.9	24.5	14.4	13.6	19.1	15.7
Sept.	12.4	11.4	13.9	12.0	8.4	11.4
Oct.	12.2	6.8	11.9	9.5	5.3	8.9
Nov.	6.5	13.5	7.4	7.8	5.2	6.8
Dec.	8.2	3.0	6.3	11.0	1.9	6.4
Total	166.7	133.5	148.5	117.9	111.7	126.0
% of pan evaporation	100%	80.08	89.08	70.73	67.01	75.58
% of precipitation	124.87	100	111.24	88.31	83.67	94.38

Various methods of approximating evapotranspiration as presented above certainly have their usefulness. Climatological information is generally sufficient for any particular locality to make the computations. However, variations in consumptive use occur from season to season or from day to day based upon parameters other than climatic conditions.

Plant physiology and morphology are factors governing consumptive use. Figure VI-18 presents a typical consumptive use and pan evaporation rates during a growing season. The consumptive use is shown to increase, reach a peak rate and then diminish. The peak rate,

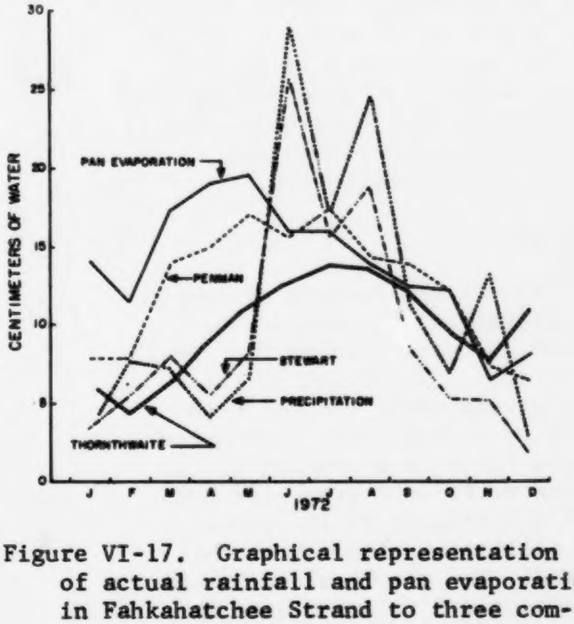


Figure VI-17. Graphical representation of actual rainfall and pan evaporation in Fahkahatchee Strand to three computed evapotranspiration methods.

season of peak rate, and period to maturity varies among types of vegetation.

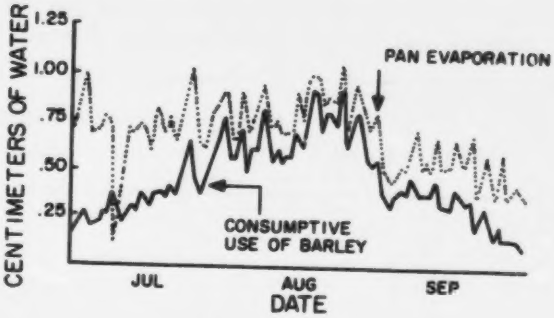


Figure VI-18. Consumptive use of water by barley and pan evaporation during a typical growing season (from Todd, 1959).

Variations in soil types, nutrients and water availability also control consumption. Stewart and Mills (1967) worked with evapotranspiration of bermuda grass and St. Augustine grass in controlled conditions. Waterproof tanks were used with controlled depth to water and controlled sod cover. During a five year period there were nine separate months of less than one inch of rain per month. Based on the data for these months the evapotranspiration for sod crops with 0.91 meter (36 in) water table (below surface) was found to be about 88 percent and 78 percent of the evapotranspiration for 0.61 meter (24 in) and 0.30 meter (12 in) water table, respectively, during relatively rainfree months. Further, plant density studies yielded the equation:

$$Y = 0.56X + 44$$

where Y = percent of full sod cover evapotranspiration

X = percent of sod cover.

Figure VI-19 shows this linear relationship. Note that the relationship does not hold near the zero percent sod cover conditions.

R. B. Sleight (1917) compared soil types to evaporation (Figure VI-20). Capillary rise in fine soils can have a large effect on evaporation and can provide water from the water table to the plants for transpiration.

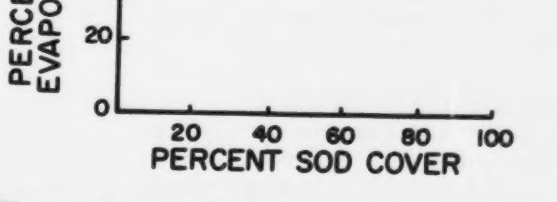


Figure VI-19. Relationship of percent of full sod evapotranspiration to percent sod cover by Stewart and Mills (1967).

Results

Direct measurement of evapotranspiration in Fahkahatchee Strand was attempted by two field techniques. The first of these used ground water table fluctuations as a measurement technique. Figure VI-21 is a tracing of the ground water well graph for EPA Well W-1 (Figure VI-1) located near Alligator Alley above the Strand. The graphical scale has been expanded to accentuate the effect of evapotranspiration on the ground water table. In this method the rate of decline of the ground water table is established by night hours, approximately 1900 to 0700. Fluctuations from this rate during the day then are due to rainfall and/or evapotranspiration assuming that other hydraulic parameters remain constant. As shown by Figure VI-21, tangents to the curve were drawn for the nighttime hours of April 2 to April 3. Without rainfall or evapotranspiration these two tangents would coincide. For April 3 the evapotranspiration amounted to 1.52 centimeters. In order to arrive at the actual amount of water that was given up from the water table the above value must be adjusted for the void ratio of the soil. A void ratio of 0.7 was chosen as being typical for sandy marl. This void ratio equates to a porosity of 0.41. The actual evapotranspiration for this date then was 0.41 x 1.52 or 0.62 centimeter.

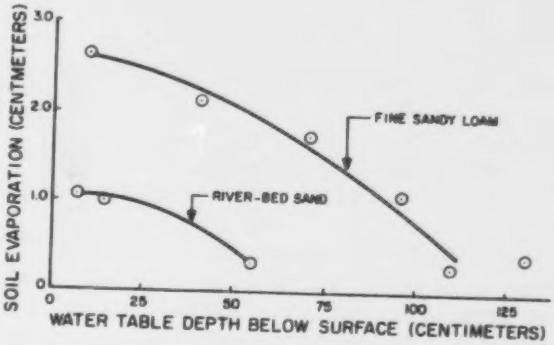


Figure VI-20. Comparison of soil types to evaporation by Sleight (1917).

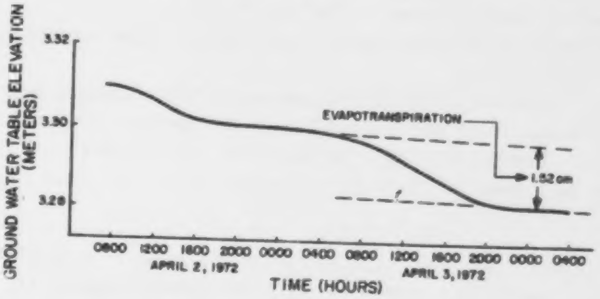


Figure VI-21. Graph of ground water levels in EPA Well W-1 showing effects of evapotranspiration.

Figure VI-22 presents a comparison of evapotranspiration from well logs to average monthly theoretical estimates from Table VI-5. The well evapotranspirations are based upon EPA Wells W-2 and W-3 adjusted for porosity. Well evapotranspiration as shown is generally higher than theoretical evapotranspirations except for two areas on the graph. The first of these areas is mid-April through mid-June and the second area is mid-August to early December. In both cases well evapotranspiration falls below theoretical. The first period (April to June) can be explained by Figure VI-23. During the period in question the vegetative covering would have to extend 80 to 120 centimeters below the ground surface to reach the ground water table and draw from it. Capillary rise reduces this depth somewhat. Based upon Taylor's relationship (1948):

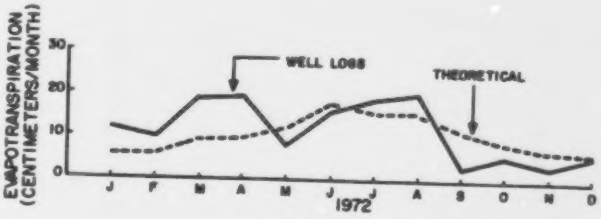


Figure VI-22. Comparison of average evapotranspiration from EPA Wells W-2 and W-3 to average monthly theoretical estimates from Table VI-5.

$$\frac{0.7}{\sqrt{K}} < h_c < \frac{2.4}{\sqrt{K}}$$

where h_c = capillary rise in cm

K = permeability in cm/sec.

The soil at both well sites is classified as fine sand with intermittent layers of muck. From Leonards (1962), who reported permeabilities of various soils, a typical value for permeability of 1×10^{-3} cm/sec was chosen. Using this value the approximate capillary rise would be 10 centimeters.

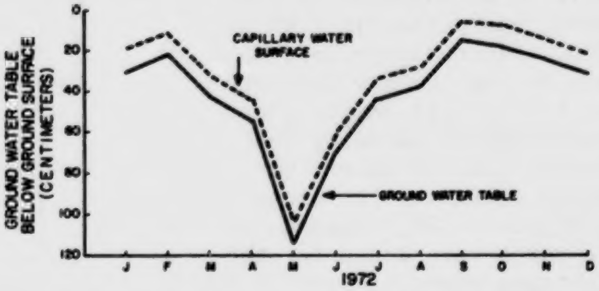


Figure VI-23. Relationship of capillary water surface to ground water table in Fahkahatchee Strand during 1972.

The second field measurement technique for evapotranspiration attempted in Fahkahatchee Strand was by means of humidity sensors. The discussion of this technique was presented in Chapter II. Data received from this technique is extremely limited and variable as depicted by Table VI-6.

Table VI -6. Comparison of prairie grass evapotranspiration measured by humidity sensors to pan evaporation in cm/day during August, 1972.

Date	Evapotranspiration	Pan Evaporation
2 (August)	0.53	0.78
3	0.86	0.82
4	0.77	0.60
7	0.82	0.42
8	0.82	0.60
9	0.44	0.60
10	0.45	0.46
11	0.70	0.46
14	0.57	0.42
15	0.55	0.32
23	0.44	0.53

Potential Evapotranspiration

The Penman (1963) method of computing potential water export attempts to evaluate the effect of radiation heat gain and the drying power of local air mass flow on evapotranspiration. The method assumes that the transport of sensible heat is controlled by temperature differences in the same way as transport of water vapor is controlled by vapor-pressure differences, arriving at an expression for water export of

$$E = (\frac{\Delta}{\gamma}H + E_a)/\frac{\Delta}{\gamma} + x$$

where E_a involves wind speed and saturation deficit, Δ is the slope of the saturation vapor-pressure curve at mean air temperature, H is the heat budget in terms of mm of water vaporizable, and γ a constant of the wet and dry bulb psychrometer equation.

This equation can be reduced to

$$E_T = \frac{\Delta H + 0.27\ E_a}{\Delta + 0.27}$$

The equation for heat budget involves a balance of input solar and cloud radiation with back radiation, as a function of cloudiness, vapor pressure, and temperature.

As we used pryheliometers to directly measure total radiation input, the cloudiness factors can be eliminated from the equation to give:

$$H = R(1-r) - \sigma T^4(0.56 - 0.092 \sqrt{e_d})$$

where H = daily heat budget in mm H_2O/day

R = mean monthly radiation input in mm H_2O/day (using 590 C/gm water evaporated)

r = reflection coefficient of surface (taken as 0.20 for forested area)

σT_4 = mm H_2O/day

e_d = saturation vapor pressure at mean dew point (i.e. actual vapor pressure in the air = e_a X R.H.) mm Hg

$$E_a = 0.35\ (1 + 0.0098\mu)\ \ (e_a - e_d)$$

where E_a = evaporation in mm H_2O/day

μ = windspeed at 2 meters above the ground (mi/day)

e_a = saturation vapor pressure at mean air temperature in mm Hg.

The data available from studies by B. Yokel in Rookery Bay were in terms of a mean windspeed averaged over the full daily cycle. In the Fahkahatchee and Rookery Bay areas, in general most of this wind occurs during daylight hours, thus it becomes a reasonable procedure to use the wind data as is and to couple it to relative humidity and temperature averages based on daylight hours. The result of this procedure is given as Table VI-7. Noon estimates of RH and $\bar{T}$ are more representative of effective air mass characteristics, as nighttime values were always fully saturated.

The mean monthly noon temperatures (° C) and water vapor pressures represent the means of the coastal station (6) on U. S. 41 and on inland station (2) located at a Florida Department of Transportation installation on S. R. 29. Data represent monthly averages, by station, of noon temperature and relative humidity, which results were then averaged to provide overall means. Both e_s, the saturation vapor pressure, and e_a, the actual vapor

Table VI -7. Climatological data for 1972, Fahkahatchee Strand area. R is the mean monthly radiation input in langleys/day, measured by a pyroheliometer (Belfort Inst. Co.) at the coastal station (6). U is the mean windspeed in kilometers per hour (provided by B. J. Yokel, Rookery Bay Project).

Month	R ly/day	u kph	e_s mm Hg	e_a R.H.$\cdot e_s$	T °C	Potential E-T mm H_2O/mo	Pan evap. mm H_2O/mo
Jan.	450 (est.)	13.97	25.36	16.34	26.1	144.8	142.9
Feb.	468.3	11.33	22.31	13.70	24.0	123.1	123.4
Mar.	503.0	15.59	26.66	15.81	27.0	177.6	172.6
April	496.7	13.40	29.02	17.84	28.4	166.8	191.9
May	539.4	12.48	32.47	19.55	30.2	198.6	202.0
June	498.7	11.60	31.82	24.46	30.0	161.7	154.6
July	535.9	9.35	33.12	24.51	30.7	180.4	160.0
Aug.	455.9	9.04	33.60	26.51	31.0	152.3	139.4
Sept.	438.2	10.06	33.60	26.42	31.0	144.1	125.8
Oct.	429.7	11.83	30.48	21.35	29.2	144.9	120.0
Nov.	330.6	7.69	25.21	18.07	26.0	79.0	69.0
Dec.	315.7	12.74	21.07	13.53	27.0	82.4	81.2

pressure, are in millimeters of mercury; e_s was derived from standard tables. Potential evapotranspiration was calculated by the Penman method and is in millimeters of water/month; pan evaporation, in the same units, represents the mean monthly evaporation from one pan at each station.

Comparison of potential evapotranspiration to pan evaporation by least squares regression for the months of February through December yielded the equation

$$\text{PAN} = 1.03\ (\text{potential}) - 11.2$$

with $P < 0.0001$. The yearly totals from the two methods are in good agreement as well. Pan evaporation totaled 1,682.8 mm, and total potential evapotranspiration was 1,755.7 mm.

Actual Evapotranspiration

Calculation of actual evapotranspiration from test well data requires a knowledge of the specific yield of the soil. One method of evaluating this characteristic of the soil utilizes a measured rise in the ground water table in response to a known input of water over a relatively large area (Todd, 1959). Paired test well and rainfall recording provided a means of estimating specific yield (Sy) by an analogous procedure. In Figure VI-24, all rainfalls greater than 0.5 inch and their associated water table rises are used to provide estimates of Sy. These estimates are plotted against the shallowness of the water table, $\bar{Z}$. Perturbation of the estimate occurs at shallow water table depths due to capillary rise and a lack of infiltration, leading to high

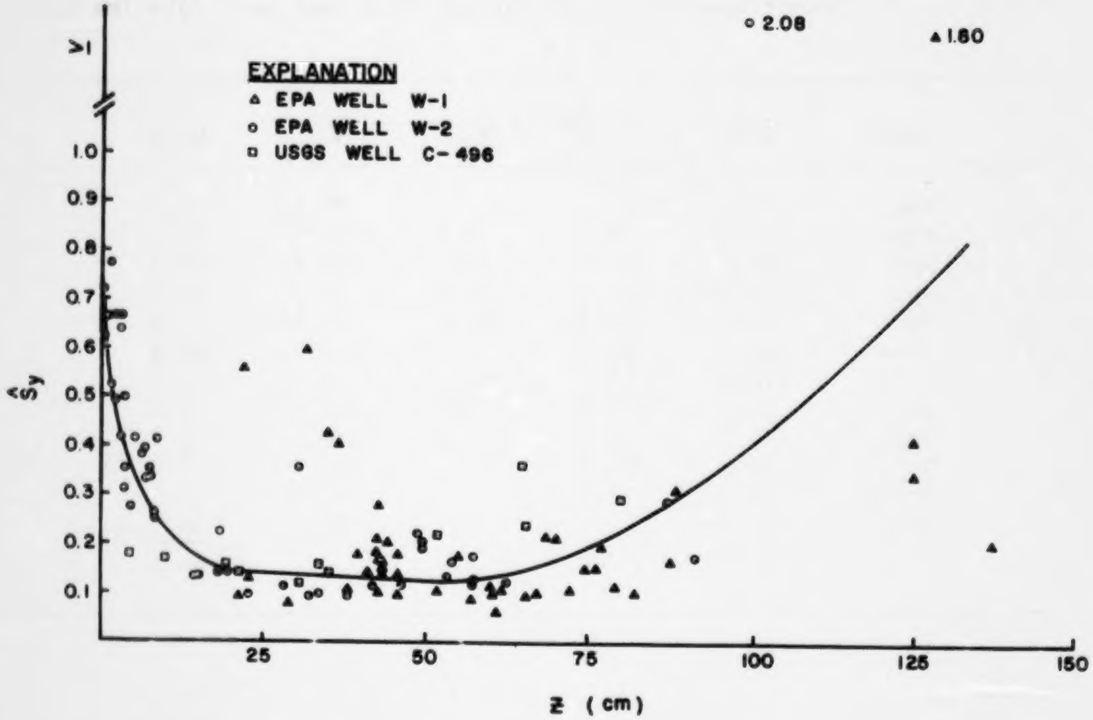


Figure VI-24. Estimated specific yield as a function of the depth of the ground water table.

estimates. Similarly, when the water table is far below ground, transpiration export of soil water reduces soil water content below field capacity. The measured estimate of specific yield is again perturbed, again resulting in artificially large values. The vest estimate of Sy from this figure, therefore, must be derived from values at an intermediate range of water table depth. In this range, most values cluster between 0.1 and 0.2, thus 0.15 was chosen as an approximate value of Sy for use in estimating consumptive water loss from test well data.

Estimation of consumptive water use from the well log data required fractionation of the data into three segments. Diel patterns of recession rates estimated water export as evapotranspiration, exclusive of water derived from field capacity. In the former case, water table changes when the water table was above ground level directly estimated evapotranspiration. Diel changes in recession rate when the water table was below ground level were corrected by the Sy (0.15) to estimate evapotranspiration. Field capacity recharge, the third component of evapotranspiration, was estimated by assuming that all rainfall would infiltrate completely when the water table was below ground level, and rainfall that failed to appear as a water table rise (using Sy = 0.15) represented field capacity recharge. The result of this procedure for four test wells is given in Table VI-8. The total evapotranspiration estimated by this procedure amounts to 1,100.2 mm of water, some 76 percent of total rainfall. The large peaks in March and June represent major field capacity recharge peaks by rainfalls following extended dry periods.

Table VI -8. Evapotranspiration calculated from test well data (mm H_2O).

Month	Well				Mean
	W-4	C-496	W-3	W-1	
Jan.		0		20.1	10.0
Feb.	23.3	90.2	19.9	27.5	40.2
Mar.	103.0	373.9	71.1	61.8	152.4
Apr.	99.7	116.5	55.9	32.5	76.2
May	70.2	91.8	94.9	46.9	75.6
June	168.3	286.3	206.0	178.1	209.6
July	116.1	217.2	144.0	63.2	135.1
Aug.	54.3	153.9	112.0	55.6	94.0
Sept.	74.7	76.2	101.8	118.0	92.7
Oct.	49.8	274.3		134.5	152.9
Nov.	39.7	39.9		-1.6	26.0
Dec.	38.5			32.5	35.5
					1,100.2

VII HYDROLOGY

INTRODUCTION

Perhaps the most discussed aspect of land development within south Florida is the effect on the natural hydrology. Due to the flatness of terrain -- gradient approximates 3 cm/km (2 inches per mile) in the Everglades system and 8 to 16 cm/km (5 to 10 inches per mile) in the Big Cypress Swamp -- surface water moves at a very slow pace. The flatness of the ground and the frictional effect of dense semi-aquatic vegetation combine to produce a southerly water flow rate of less than 0.8 km/day (0.5 miles per day) in the Big Cypress Swamp and less than 0.5 km/day (0.3 miles per day) in the Everglades. This flatness and subsequent slow runoff rate necessitates alterations to the natural system in order for man to exist and dominate in a system unnatural to his liking. Man's basic alterations consist of dredge and fill. The dredging procedures create drainage canals to remove surface and subsurface water at a more rapid than normal rate. The drainage canals often increase the flow velocity approximately one order of magnitude. Fill operations create topographic relief that expedites runoff to the canals, decreases the area of potential inundation and interrupts "sheet flow."

The network of canals within the Big Cypress Swamp is very efficient at producing results, i.e., lowering of the ground water table. The U. S. Geological Survey (USGS) (Klein, et al., 1970) found that water levels have been lowered 61 to 122 centimeters (2 to 4 feet) in a 54 square-mile area east of Naples.

UPLAND HYDROLOGY

Methods

Stevens Type A Model 71 stage recorders were used to provide continuous records of stage at both surface and ground water stations throughout the study area. Rating curves of flow versus stage were developed for the total flow crossing Janes Scenic Drive at some 34 stations consisting of 8 bridges and 34 culverts. Measurements were generally made on a monthly basis or whenever there was a sufficiently significant increase or decrease in stage to warrant a measurement. The rating curve is inclusive for all stations located within line sigment 1-4 on Figure VII-1.

An additional rating curve was developed for a measurable cross section of Fahkahatchee Strand which included a portion of Janes Scenic Drive and a tramway known locally as West Main shown as line segment 2-3 on Figure VII-1. This rating curve consisted of flows at one bridge and 22 culverts on Janes Scenic Drive, 4 bridges and 1 culvert on West Main in addition to flow around the western end of West Main. Information obtained from this section was of prime value in determining areas of inundation in the southern end of Fahkahatchee Strand.

Alligator Alley rating stations consisted of two culverts and three bridges located west of SR 29 and east of the eastern-most GAC canal.

Stations A, B and C (Figure VII-1) were used to measure direct ground water contributions to a portion of the GAC canals. Station A is located

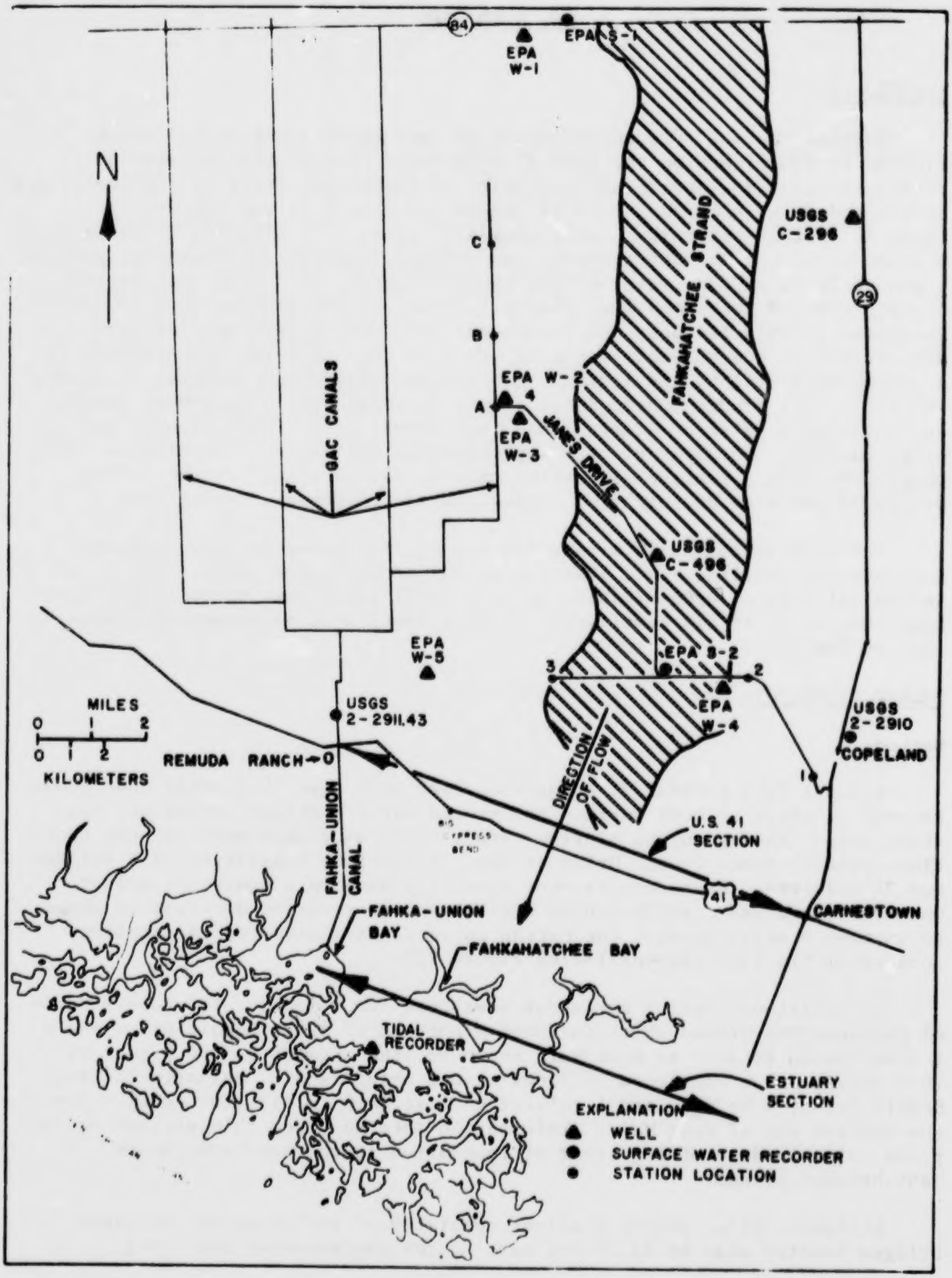

84
EPA S-1
EPA W-1
N
C
B
A
EPA W-2
4
EPA W-3
JANE'S DRIVE
FAHKAHATCHEE STRAND
USGS C-296
29
GAC CANALS
USGS C-496
EPA W-5
3
EPA S-2
2
EPA W-4
USGS 2-2910
COPELAND
1
MILES
0 1 2
0 1 2
KILOMETERS
USGS 2-2911.43
REMUDA RANCH
0
FAHKA-UNION CANAL
BIG CYPRESS BEND
DIRECTION OF FLOW
U.S. 41 SECTION
41
CARNESTOWN
FAHKA-UNION BAY
FAHKAHATCHEE BAY
TIDAL RECORDER
ESTUARY SECTION
EXPLANATION
▲ WELL
● SURFACE WATER RECORDER
• STATION LOCATION

Figure VII-1. Map of Study Area Showing Hydrology Stations.

at the intersection of Janes Scenic Drive and the eastermost GAC canal. Stations B and C are located 1.61 and 5.23 kilometers (1.0 and 3.25 miles) north of Station A.

Results

Surface Water

As discussed in Section VI the year 1972 would be described as an above average year for rainfall. However, surface water flows and ground water levels appear to be less than average.

Total flow for the year amounted to approximately 357,712 cubic meters (2,900 Ac-Ft) with a maximum daily discharge of 1,189 liters/sec (42 cfs) being observed on February 12 (Figure VII-2). During 65 percent of the year there was no measurable flow. No flow occurred from February 24 until August 28, a time lapse of over six months. The average daily flow for the year amounted to less than 113 liters/sec (4 cfs). Partially due to the low flow characteristics throughout the year a profuse growth of aquatic and semi-aquatic vegetation has occurred at all bridges. This vegetative growth has progressed to the point that it inhibits much of the natural flow north of Alligator Alley from entering Fahkahatchee Strand. During 1972, less than 17 percent of the flow crossing Janes Drive can be attributed to input from north of Alligator Alley.

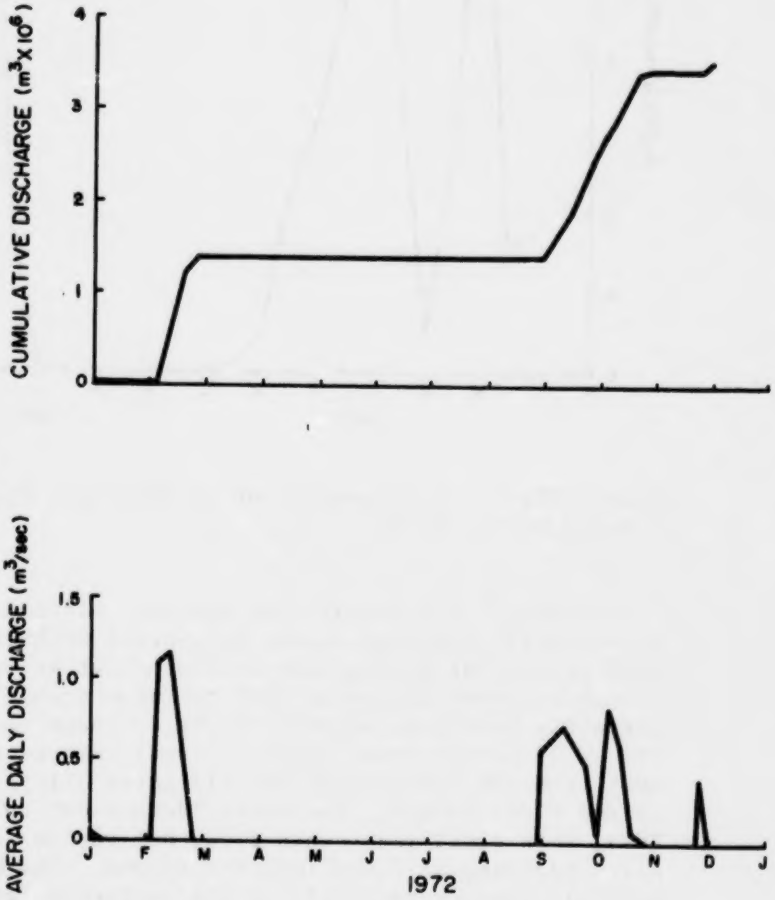


Figure VII-2. Hydrograph and Cumulative Discharge for Alligator Alley Between SR 29 and the easternmost GAC canal.

Compared to recent years, a minimal amount of flow crossed Janes Scenic Drive during 1972 (Figure VII-3). For the years 1970, 1971 and 1972 a total of 194,568,240 cubic meters, 111,661,680 cubic meters, and 20,112,054 cubic meters (157,738 Ac-Ft, 90,525 Ac-Ft and 16,305 Ac-Ft), respectively, crossed Janes Scenic Drive. No measurable flow passed Janes Scenic Drive from March 10 until August 13 (Figures VII-4 and 5). A peak flow of 7,419 liters/sec (262 cfs) occurred on November 12 and 13.

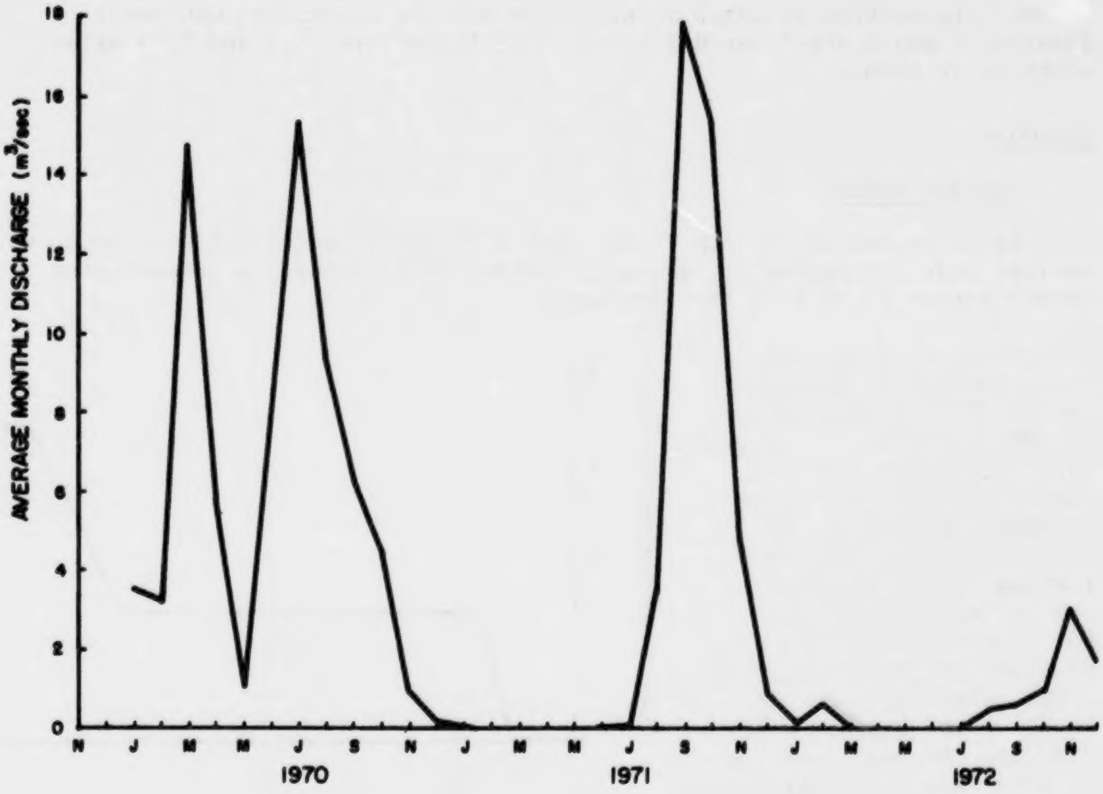


Figure VII-3. Hydrographic of Monthly Mean Discharge of Flows Passing Janes Scenic Drive.

Figure VII-6 reveals the special relationship of Fahkahatchee Strand to the major drainage canals in central Collier County. Records from the USGS and aerial photographs indicate that at one time the Okaloacoochee Slough was hydrologically tied to Fahkahatchee Strand. These ties must certainly have been altered by the drainage canals shown on this figure. The SR 29 borrow canal (Barron River) intercepts and diverts major flows away from the Strand. SR 84 (Alligator Alley) borrow canal intercepts upland flow; however, the canal "dead ends" on either side of the Strand. Thus, this canal intercepts flow, but various structures along its reach allow passpage of flows into the Strand. The GAC canal system to the west probably intercepts little of the surface water flow to Fahkahatchee Strand. These canals, however, intercept surface flows to other areas to the southwest and they also draw heavily on the ground water (discussed later in this Section).

Massive quantities of water are transported from the inland areas to Fahka Union Bay via the GAC system of canals. The canals drain approximately 81,000 hectares (200,000 acres) in Collier County. Fahka Union Bay receives direct drainage from as far north as Corkscrew Swamp, some 51.5 kilometers (32 miles) away. The total flow of Fahka Union Canal at Remuda Ranch decreased to 177,263,000 cubic meters (143,708 Ac-Ft) in 1972 from

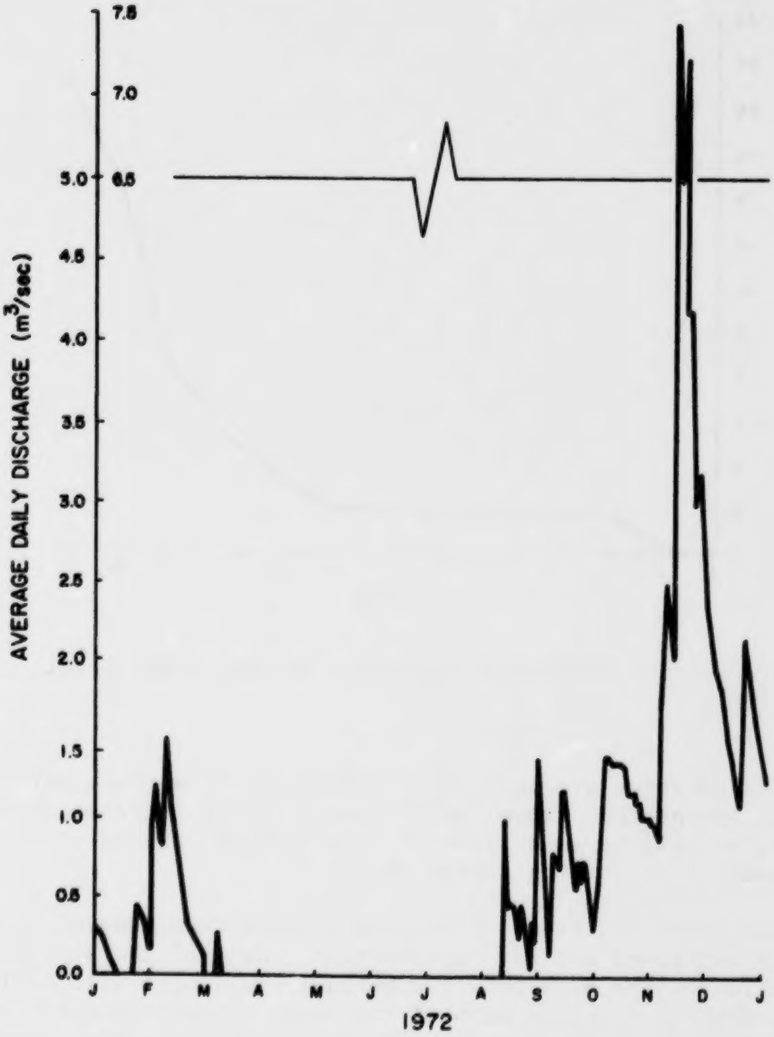


Figure VII-4. Hydrograph of Flows Passing Janes Scenic Drive.

339,481,110 cubic meters and 342,207,130 cubic meters (275,222 Ac-Ft and 277,430 Ac-Ft) in 1970 and 1971, respectively (Figure VII-7). Assuming an average water consumption of 379 liters per capita per day (100 gpcpd), the discharge from Fahka Union Canal would have supported 2.45 million persons, 2.47 million persons and 1.35 million persons in 1970, 1971, and 1972, respectively. It is interesting to note that the total population of Collier County is less than 40,000.

The decrease of surface flow in the Fahka Union Canal during 1972 is not in itself a complete picture of the situation. This year followed an extremely dry period. Rainfall during 1970 and 1971 at Everglades City was 119.5 and 112.2 centimeters, respectively, or some 44.7 centimeters below the long-term average. Rainfall during 1972 was 157.1 centimeters

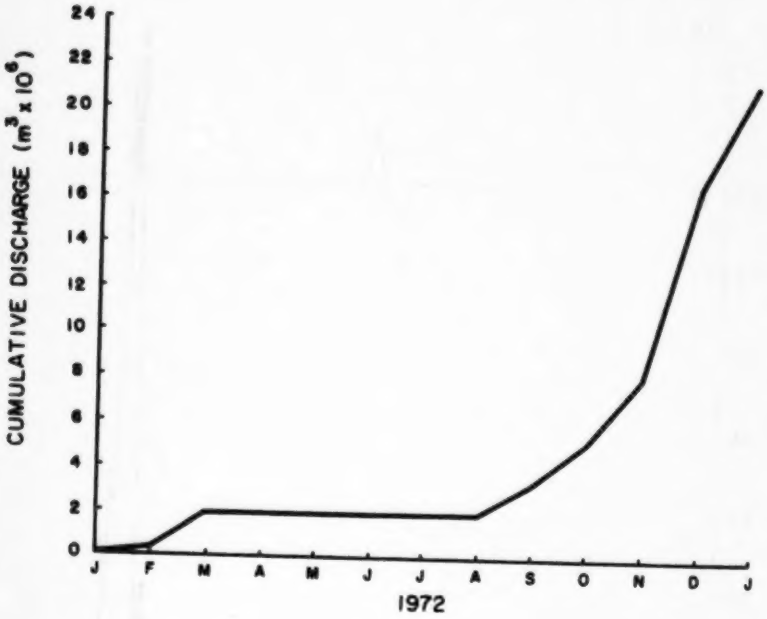
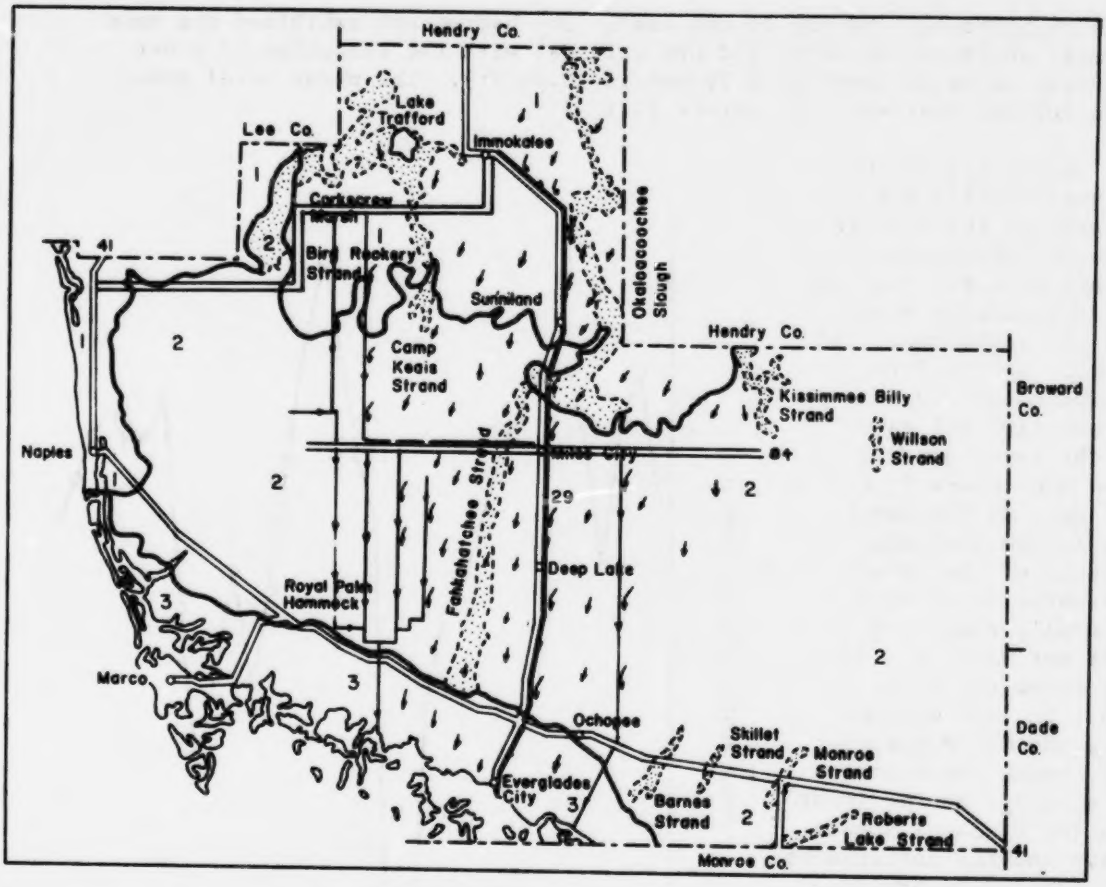


Figure VII-5. Cumulative Discharge Passing Janes Scenic Drive.

or 19.9 centimeters above average. With a decrease in surface water discharge it would appear that ground water levels should increase during 1972. However, as will be seen later in this section, ground water levels decreased instead of increasing during 1972.

Much of the flora and fauna of the Big Cypress Swamp depend upon the hydroperiod for existence and for reproduction. Many of the amphibians require inundation of the area before previously laid eggs will begin to hatch. During the rainy season much of the swamp becomes inundated and remains so for several months following a normal rainfall year. Approximately 10 percent of the area remains inundated year round.

A large portion (Figures VII-8 and 9) of the study area remained relatively dry throughout 1972. Approximately 37 percent of the study area above US 41 was inundated during January and February. The inundated area decreased to 20 percent in March and 4 percent in April. During May, June, July and August there were no significant areas inundated within the Fahkahatchee Strand study area. The only areas which contained water were the canals and a few scattered ponds within Fahkahatchee Strand. Following the heavy rains of June the interior of Fahkahatchee Strand became inundated to a depth of approximately 12 centimeters (4 in). However, some ten days later the water had receded below the ground surface and remained so until August 27. The area of inundation increased rapidly during September and peaked during November. A slight decrease occurred in December. The percent of the study area inundated during September, October, November and December was 35, 45, 51, and 45, respectively. Because of the inaccessability of much of the area north of US 41 and south of Janes Scenic Drive the area of inundation is not completely delineated in Figures VII-8 and 9.


Hendry Co.
Lake Trafford
Lee Co.
Immokalee
1
1
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1
2
Corkscrew Marsh
Bird Rookery Strand
41
Sunniland
Okaloacoochee Slough
Hendry Co.
2
Camp Keais Strand
Kissimmee Billy Strand
Broward Co.
Willson Strand
Naples
Miles City
84
2
2
29
Fahkahatchee Strand
Deep Lake
Royal Palm Hammock
3
Marco
3
2
Ochopee
Skillet Strand
Monroe Strand
Dade Co.
Everglades City
3
Barnes Strand
2
Roberts Lake Strand
41
Monroe Co.

Fibure VII-6. Major Drainage Canals Near Fahkahatchee Strand.

Groundwater

The seven hydrographs in Figures VII-10 to 15 represent variations in ground water levels throughout the study area. The seven well sites are representative of the study area above US 41. The ground elevation presented in each figure is the average of four to six elevations obtained within 100 meters of the well site.

EPA Well No. W-1 (Figure VII-10) is located at the northwest corner of the study area approximately 152 meters (500 ft) south of Alligator Alley. With the exception of the first 23 days of November 1971 the ground water was below surface. The ground water level continued to fall until the first of June when, due to the increased rainfall, the level began to rise. The maximum drawdown during 1972 was 1.48 meters (4.86 ft). A net decrease in water level of 0.36 meters (1.19 ft) occurred during 1972. The maximum distance below the surface was 1.48 meters (4.86 ft) on June 1, 1972.

The water level at USGS Well C-296 (Figure VII-11) was affected by the operation of stop-log controls which regulate flow in the Barron River Canal some 30.5 meters (100 ft) to the east. The hydrograph exhibited the same general characteristics as did EPA Well W-1 with the exception of a net increase in water level of 0.29 meters (0.94 ft). The water level drawdown for the year was 1.26 meters (4.13 ft).

Wells W-2 and W-3 (Figure VII-12) are located at the western edge of Fahkahatchee Strand near the junction of Janes Scenic Drive and the easternmost GAC canal. Well W-2 is approximately 30.5 meters (100 ft) east of the canal and W-3 some 320 meters (1,050 ft) east of the canal. Due to the drainage effects of the canal, the water level at W-2 generally remains 0.12 - 0.18 meters (0.4 - 0.6 ft) below the level at W-3. In late October 1972 the GAC Properties, Inc. began construction of a bridge at the intersection of Janes Scenic Drive and the easternmost GAC canal. In preparation for the footings of the bridge the canal was diverted and a sump was dug at the canal site. Several large pumps were installed in order to remove ground water from the sump. On October 30, 1972, at 1300 hours the water level in the sump was 1.54 meters (5.06 ft) below MSL. Ground water elevation at W-2 was 0.43 meters (1.41 ft) above MSL and W-3 at 1.27 (4.17 ft) above MSL. Level of water in the diversion canal immediately adjacent to the sump was 1.34 meters (4.38 ft) above MSL. Due to the pumping effect, Well W-2 had a net decrease in water level of 0.90 meters (2.94 ft) during 1972. The net decrease at W-3 was 0.41 meters (1.34 ft). The maximum elevation observed at W-2 was 2.23 meters (7.30 ft) on June 18 and a minimum of 0.27 meters (0.90 ft) on November 12. By observing the vegetation in the immediate vicinity of W-2 and W-3 it can be concluded that this area was frequently inundated in the past. The area was inundated during a portion of late summer in 1971. Visual inspection

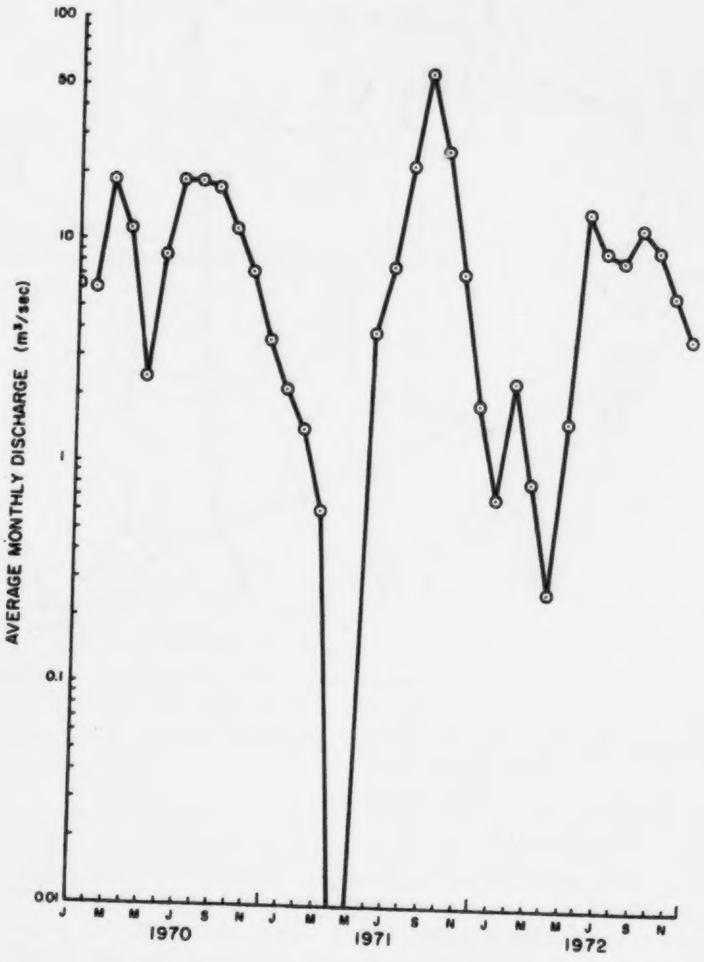
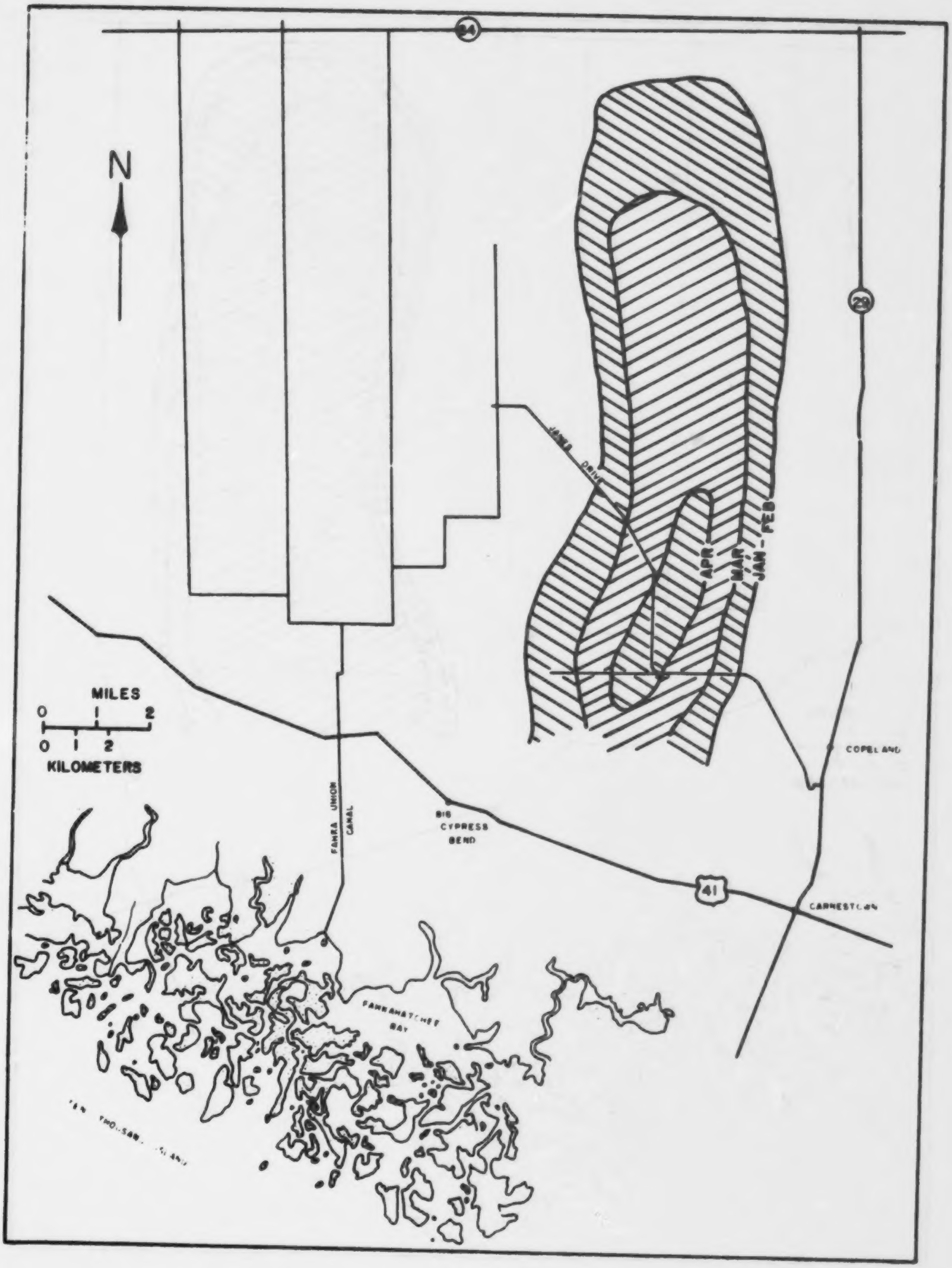


Figure VII-7. Hydrograph of Monthly Mean Discharge of the GAC Canal System at Remuda Ranch.


84
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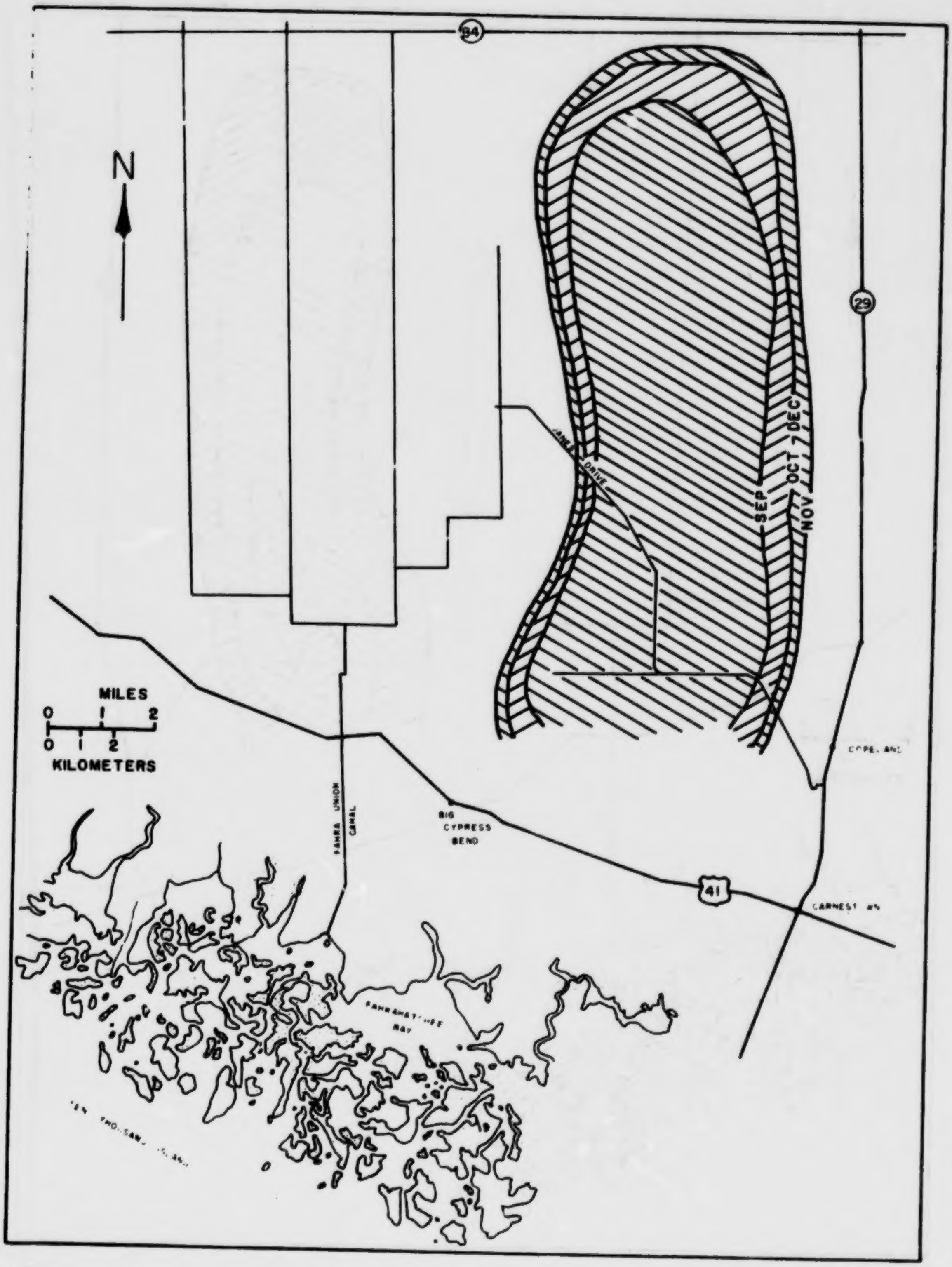
29
COPELAND
FAHKA UNION CANAL
BIG CYPRESS BEND
41
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS

Figure VII-8. Inundated Areas of Fahkahatchee Strand From January - June 1972 (Cross-Hatching Represents Areas of Standing Water).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0 1 2
KILOMETERS
FAHKA UNION CANAL
BIG CYPRESS BEND
41
COPELAND
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS

Figure VII-9. Inundated Areas of Fahkahatchee Strand From July - December 1972. (Cross-Hatching Represents Areas of Standing Water.)

during that time revealed that the easternmost GAC canal was intercepting surface water from the Fahkahatchee Strand side of the canal. As designed, the canal very rapidly removed the surface water and lowered the ground water table. During 1972 the water table was always lower than 0.54 meters (1.77 ft) and 0.49 meters (1.62 ft) below the ground elevation at W-2 and W-3, respectively.

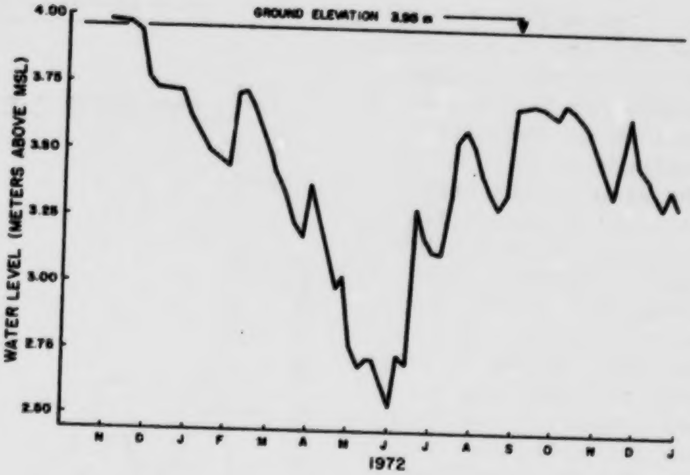


Figure VII-10. Hydrograph of EPA Well W-1.

USGS Well C-496 is located on Janes Scenic Drive near the center of Fahkahatchee Strand. The Strand at this site (Figure VII-13) is generally inundated with the exception of extreme dry periods. During 1972 the area was not inundated from April to September except for several days in July following heavy rains. On June 1 the ground water receded to 0.90 meters (2.96 ft) above MSL some 0.79 meters (2.60 ft) below the surface. The main slough of Fahkahatchee Strand was inundated from January through May with a maximum water depth of 0.36 meters (1.18 ft) on January 1. The slough was again inundated from August 27 until the end of the year with a maximum depth of 0.44 meter (1.45 ft) on November 18. A net decrease in water level of 0.05 meter (0.16 ft) occurred during the year.

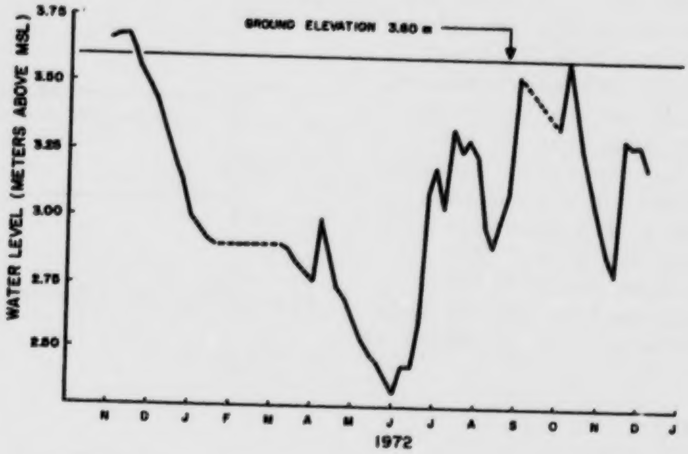


Figure VII-11. Hydrograph of USGS Well C-296.

EPA Well W-4 is located on Janes Scenic Drive near the eastern edge of Fahkahatchee Strand. The ground water levels (Figure VII-14) exhibited the same general characteristics as USGS Well C-496. However, inundation did not occur until August 26 with a maximum depth of 0.09 meter (0.30 ft) on September 1. The maximum depth to the water table below the surface was 1.16 meters (3.79 ft) on June 1.

EPA Well W-5 (Figure VII-15) is located on an access road to the Remuda Ranch pumping station at the same latitude as Well W-4. The area is classified as a wet prairie (low lying areas of Ochopee marl or Ochopee fine sandy marl consisting mainly of short grasses). However, during 1972 the area was anything but a wet prairie. The prairie was inundated for approximately 25 days during portions of June, August, and September with a maximum depth of 0.11 meter (0.35 ft) on June 18. The minimum level of the ground water table was 0.17 meter (0.55 ft) above MSL or 1.02 meters (3.36 ft) below ground on May 1. A net increase in water level of 0.16 meters (0.51 ft) occurred during the year. With ground water levels approaching MSL at this location the possibility of salt water intrusion exists in the area. Assuming that ground water levels do not increase downstream from this site, the expected interface between fresh and saline water on May 1 would occur some 6.8 meters (22.0 ft) below the surface, based upon the Ghyben-Herzberg principal that for each foot of water which occurs above MSL 40 feet of fresh water occurs below MSL.

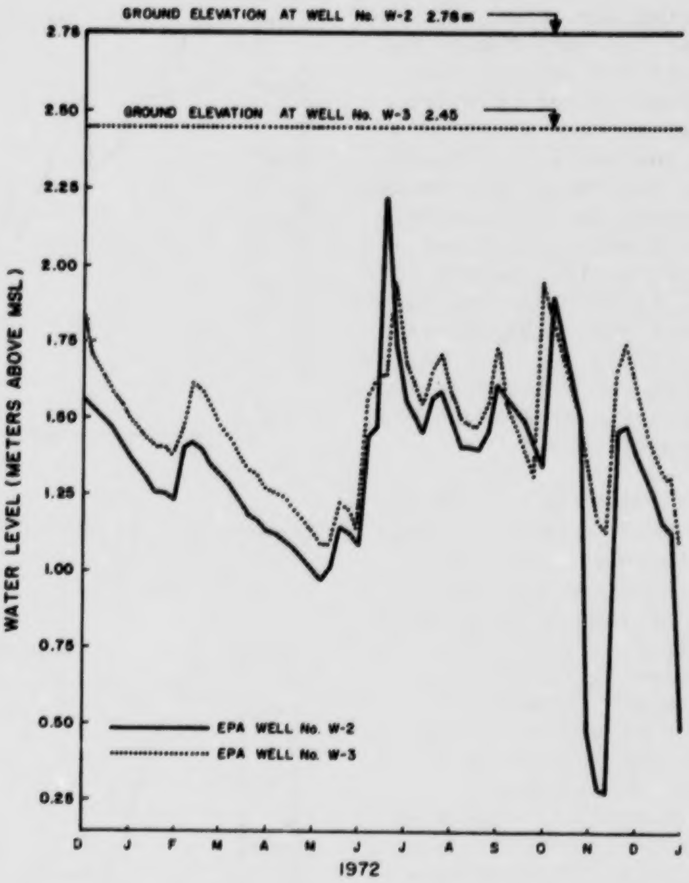


Figure VII-12. Hydrograph of EPA Wells W-2 and W-3.

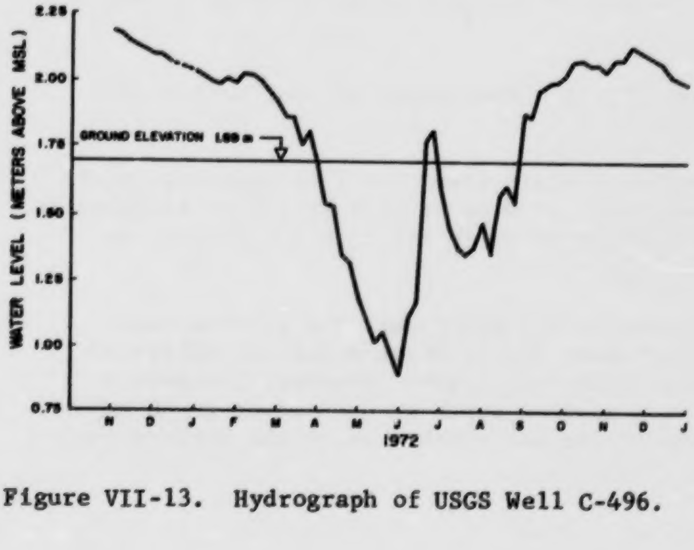


Figure VII-13. Hydrograph of USGS Well C-496.

The elevation of the top of the weir on the

Fahka Union Canal immediately downstream from USGS surface water gaging station 2-2911.43 (Figure VII-1) is 0.61 meter (2.0 ft) above MSL. EPA Well W-5 is 2.1 kilometers (1.3 miles) east of the body of water impounded by the weir. As observed by Figure VII-15 the ground water elevation at EPA Well W-5 was less than 0.61 meter (2.0 ft) during part of January, February, March, May, November and December, in addition to the entire month of April in 1972. With the exception of sixteen days from April 21 to May 6, 1972, the elevation of the water surface in the canal at USGS stage recorder 2-2911.43 (Figure VII-1) was 0.61 meter (2.0 ft) above MSL or higher. The water surface elevation in the canal fell to a minimum of 0.52 meter (1.71 ft) above MSL on May 5. The water elevation in EPA Well W-5 fell to a minimum of 0.17 meter (0.55 ft) above MSL on the same date. Based on a positive differential in stage between the canal and EPA Well W-5 ground water recharge may be occurring during a portion of the year.

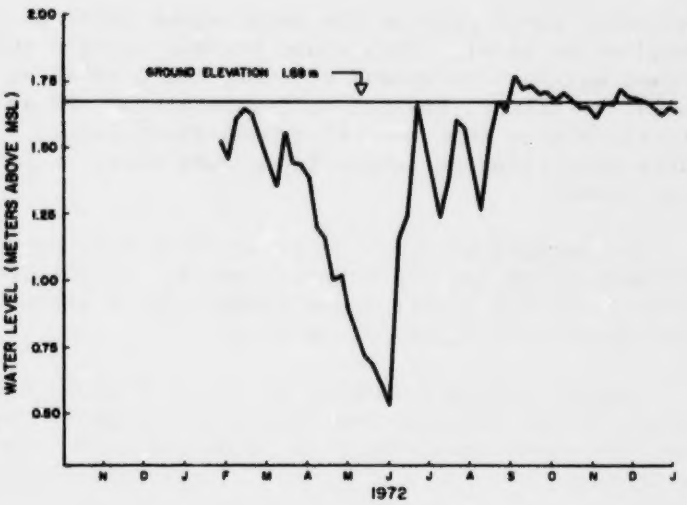


Figure VII-14. Hydrograph of EPA Well W-4.

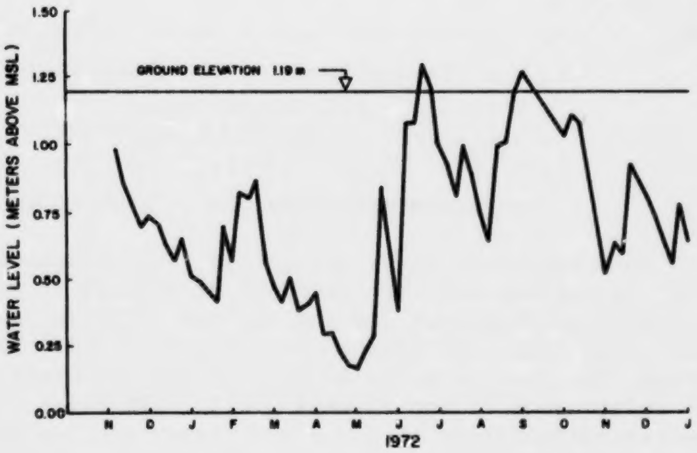


Figure VII-15. Hydrograph of EPA Well W-5.

In a report (Gee and Jenson, 1970) prepared by a consulting engineering firm for GAC Properties, Inc., the following statement appears on page 9. "However, a review of the proposed development south of Alligator Alley and east of the natural divide indicates that a canal should be constructed on the east boundary of the development to assist the natural flow of water southward into the Strand." The results of such action would be to induce removal of water out of the Strand at approximately one order of magnitude faster than normal during the hydroperiod. As such, canals in Collier County are designed, constructed, maintained, and operated to rapidly remove surface water and lower ground water levels. However, during the dry winter months canals may be usable as ground water recharge sources. For this to take place would require the canal water level to be higher than the surrounding ground water level. This would further require the importation of ground or surface waters from upland sources, via a canal network, into the Strand. Canals, by nature, are not self-substaining and as separate entities cannot maintain higher than natural ground water levels. Thus, the usefulness of canals as a recharge source for ground water in Fahkahatchee Strand is questionable.

The merging of fresh water aquifers and the Gulf of Mexico is an extremely important and complex system. In this study we investigated the possible effects of the ocean dynamics at a ground water well (W-6) located approximately two miles above US 41.

Coastal aquifers respond to the sinusoidal dynamics of the tides. Effects of the tidal movements are proportional to the amplitude of the tide, the duration of the tide, distance inland, storage coefficient of the aquifer, and the coefficient of transmissibility of the aquifer.

A relationship has been developed (Todd, 1959) that yields the amplitude of the fluctuations of the ground water table at any distance from the shore. This amplitude is expressed as:

$$h_x = h_o e^{-x\sqrt{\pi s/t_o T}}$$

where h_x = ground water amplitude at distance x from shore

h_o = tidal amplitude at the shore in feet

X = distance from shore in feet

s = aquifer storage coefficient

t_o = tidal period in days

T = transmissibility of the aquifer in gallons/day/foot

In a report of wells and ground water resources in Collier County (Klein, 1954), a transmissibility value of 92,000 gpd/ft and a storage coefficient of 0.001 was developed for the shallow artesian aquifer existing at the Naples well field. He also related in his report that the semi-impermeable stratum between the shallow artesian aquifer and the upper non-artesian aquifer may not exist south of Naples well field. EPA Wells 2 and 3 were used to compute the transmissibility of the non-artesian aquifer at their site which is at the western edge of the Strand. The transmissibility was 4.1 cm/sec based upon three observations. Since this value is quite similar to Klein's, a transmissibility of 4.3 cm/sec and a storage coefficient of 0.001 was used. Figure VII-16 was developed using these values, along with a tidal period (high to low) of six hours and a tidal amplitude or half range of 0.43 meter (1.4 ft). As seen from this figure, tidal effects on ground water table is rapidly dampened inland from the shore. A tidal range of 0.91 meter (3.0 ft) produces only a 0.86 centimeter (0.34 inch) fluctuation in the ground water table 3.22 kilometers (2 miles) inland.

Todd also demonstrated a relationship for the time lag of a given maximum or minimum tide at the ocean to the time that this effect is seen inland. The time lag is: $t_L = x\sqrt{t_o S/4\pi T}$. This relationship is shown on Figure VII-17 as a plot of time lag in hours versus kilometers inland from shore. At 3.22 kilometers (2.0 miles) inland the time lag is approximately 3.75 hours.

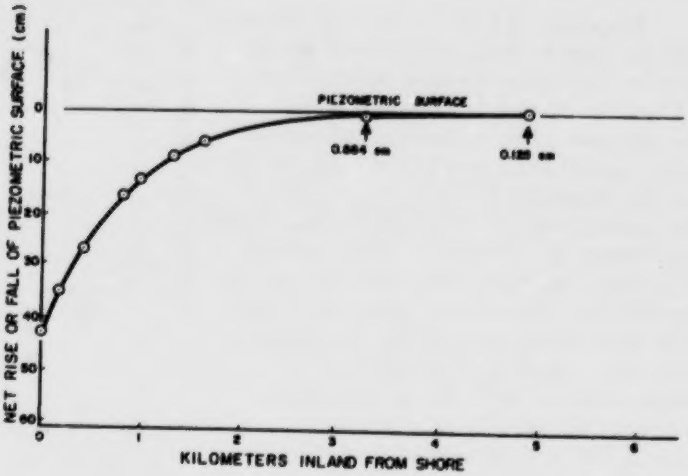


Figure VII-16. Net Change of Piezometric Surface Inland From the Ocean.

Figure VII-18 is a graph of ground water levels at EPA Well W-5 for December 8-9, 1972. This well is located 3.22 - 4.02 kilometers (2 - 2.5 miles) above the tidally influenced portion of the Fahka Union Canal. This graph clearly shows a response to the tidal fluctuations. Responses during daylight hours are overpowered by evapotranspiration as shown by the log for the daylight period of 0700 - 1800 on December 8. However, early morning responses to flood tides are shown to produce a range of 0.76 centimeter (0.025 ft) or amplitude (h) of 0.38 centimeter (0.0125 ft). Entering this amplitude into Figure VII-16, a value of 3.86 kilometers (2.4 miles) inland is received. Thus, the response of the well log during low transpiration interferences compares favorably with the calculated response. Klein, during pumping test of the old Naples well field, noticed responses of the wells to tidal movement. He reported a time lag of 1.5 hours and a daily fluctuation range of 6 to 21 centimeters (0.2 to 0.7 ft) for a well located 0.86 kilometers from shore. The water level in this well, however, was influenced somewhat by well field pumping. Figures VII-16 and 17 give a value of 0.9 hour time lag and a tidal range of 0.34 meters (1.1 ft) or 0.17 meters (0.55 ft) = h. Again, field measured values and calculated values favorably compare.

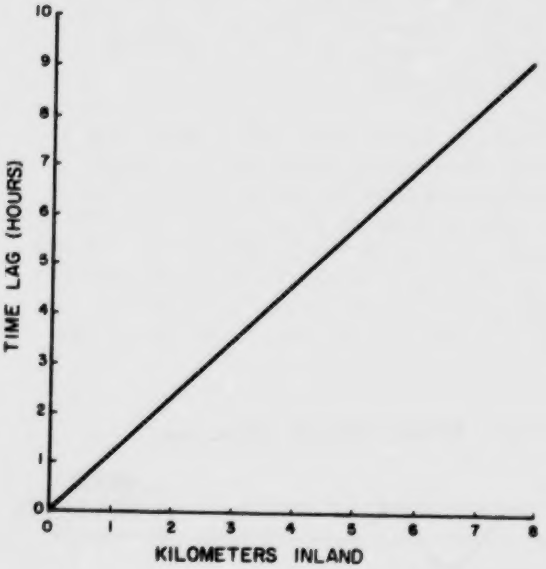


Figure VII-17. Time Lag of Tidal Effect on Ground Water Levels Inland From the Ocean.

Figure VII-19 is a graphical representation of the dynamics of piezometric surface. Although tidal caused fluctuations of ground water levels are of little significance in the overall hydrology they do create problems in direct measurement of evapotranspiration at specific locations.

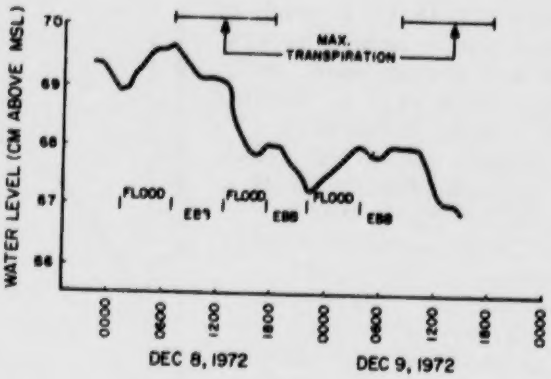


Figure VII-18. General Response of Piezometric Surface to Tidal Effects.

Figures VII-20, 21, and 22 are contour maps showing ground water levels in Fahkahatchee Strand on different dates. It should be recognized that a number of ground water gradients could be constructed in Figures VII-20, 21, and 22. The ground water gradients as shown are based on straight line extrapolation between the various wells. Therefore, flow line analysis and flow net analysis would be inconclusive. During November 1971 water levels were at a maximum, decreasing to a minimum in June 1972 and again maximizing in October 1972. The most pronounced effect of the GAC drainage canals on water levels is exhibited at the intersection of Janes Scenic Drive and the easternmost canal near wells W-2 and W-3. On November 8, 1971, (Figure VII-20) the 2.00 meter ground water contour is approximately 6.5 kilometers north of the expected location of the contour. Without the canal, the water level at the same latitude would be approximately 3.1 meters. In the center of Fahkahatchee Strand the hydraulic gradient decreases approximately 0.12 m/km compared to 0.16 m/km near the canal. The same general characteristics are evident on June 14 and October 10.

Ground water recession rates are greater in areas near the canals than in areas distant from canals. Figure VII-23 presents ground water levels for approximately seven days following hurricane Agnes in June 1972. During June 16, 17 and 18, Fahkahatchee Strand received from 14.0 to 16.5 centimeters (5.5 to 6.5 inches) of rain. Ground water levels peaked at most wells on the afternoon of June 18. The recession rate at EPA Well W-2 was 9.1 centimeters per day (0.30 ft/day) for the five days immediately following the peak in ground water stage. This rate of 9.1 centimeters per day near the GAC Canal

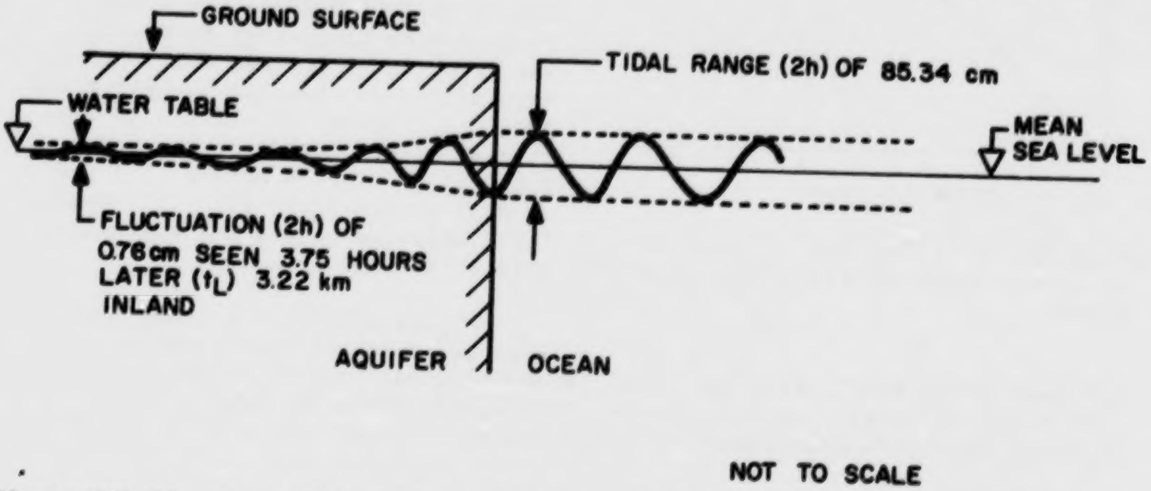

GROUND SURFACE
TIDAL RANGE (2h) OF 85.34 cm
WATER TABLE
MEAN SEA LEVEL
FLUCTUATION (2h) OF 0.76cm SEEN 3.75 HOURS LATER (t_L) 3.22 km INLAND
AQUIFER
OCEAN
NOT TO SCALE

Figure VII-19. General Response of Piezometric Surface to Tidal Response

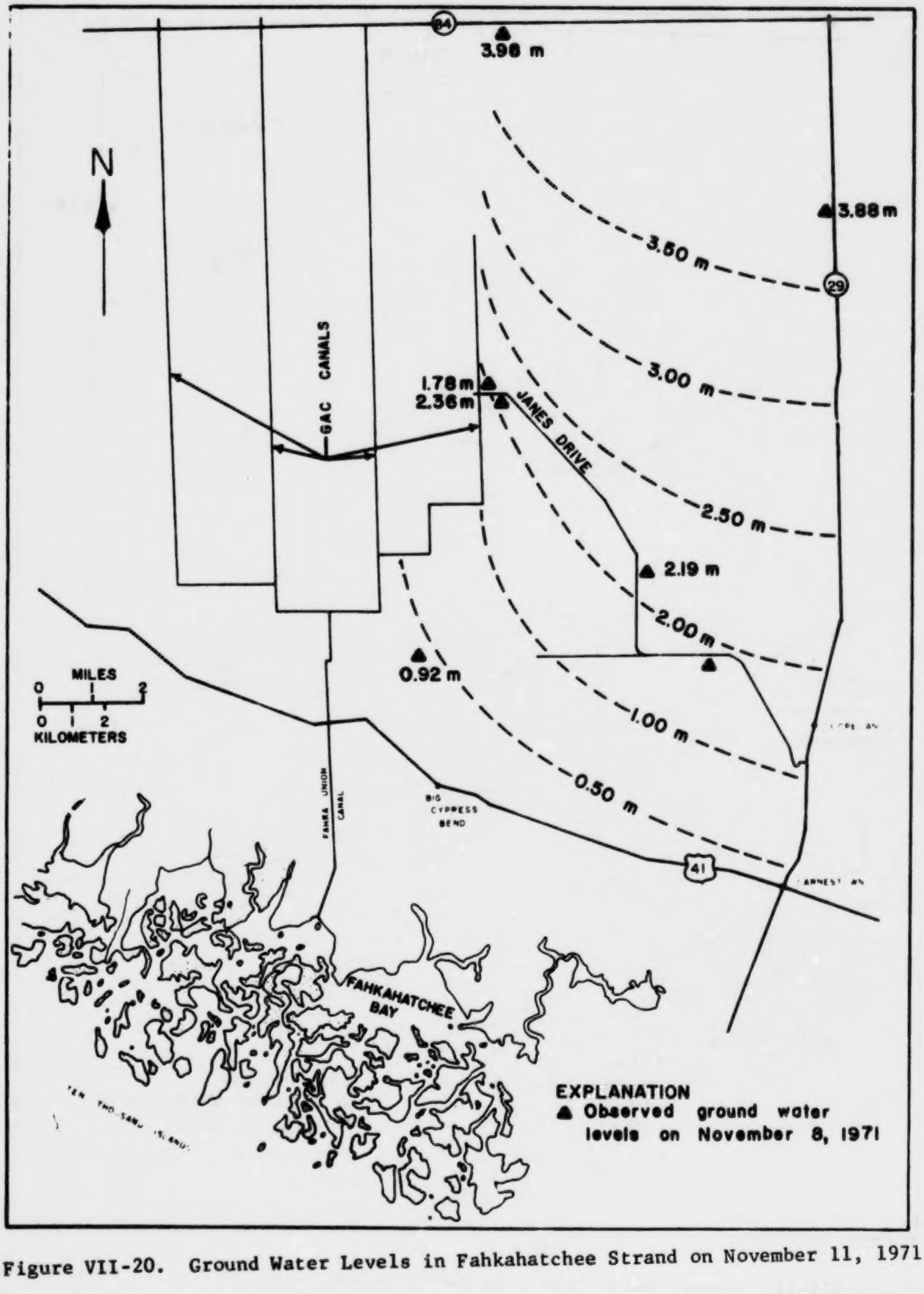

84
3.98 m
N
3.88 m
3.50 m
29
GAC CANALS
1.78 m
2.36 m
JANES DRIVE
3.00 m
2.50 m
2.19 m
2.00 m
0.92 m
1.00 m
0.50 m
MILES
0 1 2
0 1 2
KILOMETERS
COPELAND
FAHKA UNION CANAL
BIG CYPRESS BEND
41
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS
EXPLANATION
▲ Observed ground water levels on November 8, 1971

Figure VII-20. Ground Water Levels in Fahkahatchee Strand on November 11, 1971.

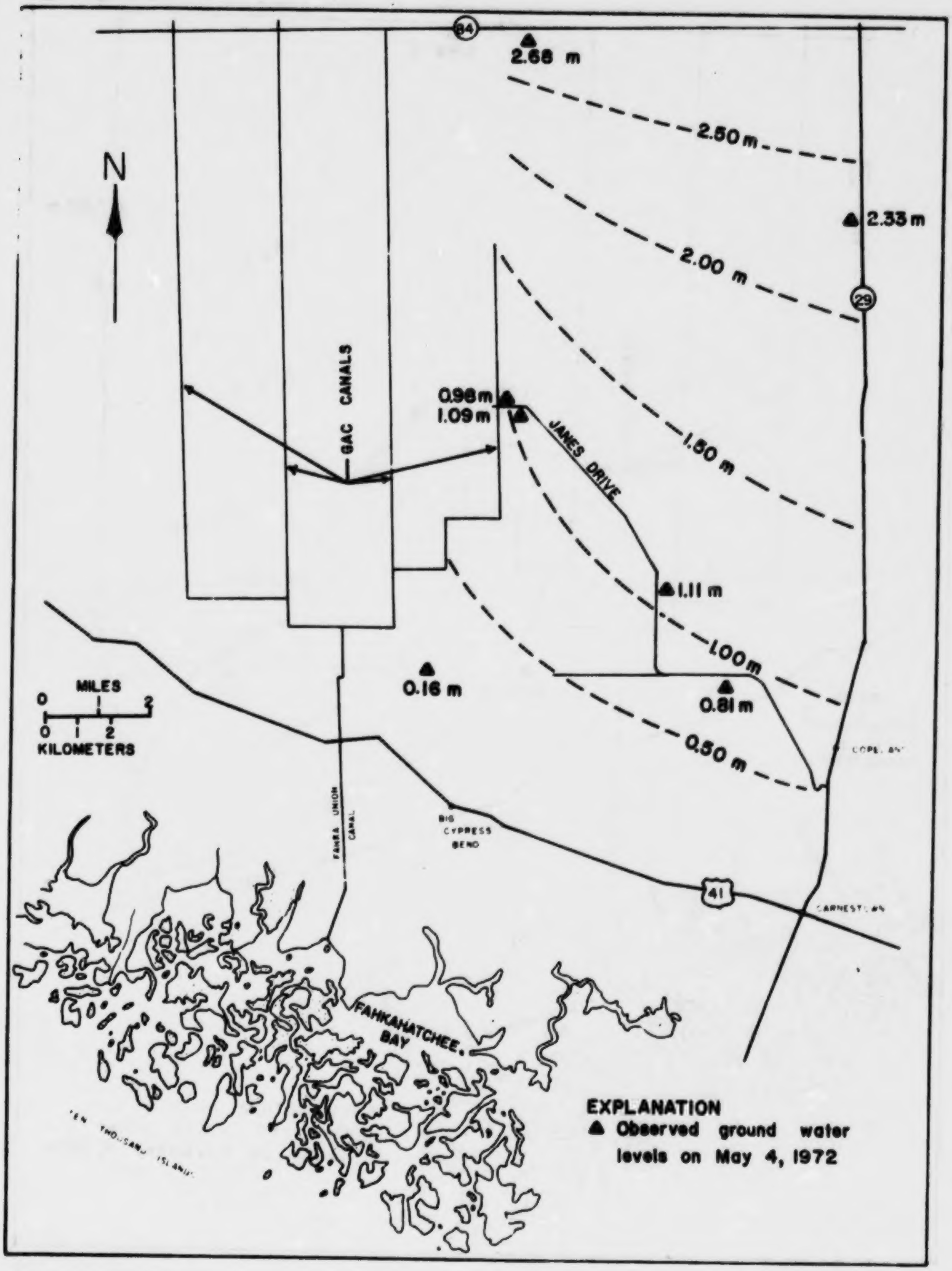

84
2.68 m
2.50 m
2.33 m
2.00 m
29
N
GAC CANALS
0.98 m
1.09 m
JANES DRIVE
1.50 m
1.11 m
1.00 m
0.81 m
0.16 m
0.50 m
MILES
0 1 2
0 1 2
KILOMETERS
COPELAND
FAHKA UNION CANAL
BIG CYPRESS BEND
41
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS
EXPLANATION
▲ Observed ground water levels on May 4, 1972

Figure VII-21. Ground Water Levels in Fahkahatchee Strand on May 4, 1972.

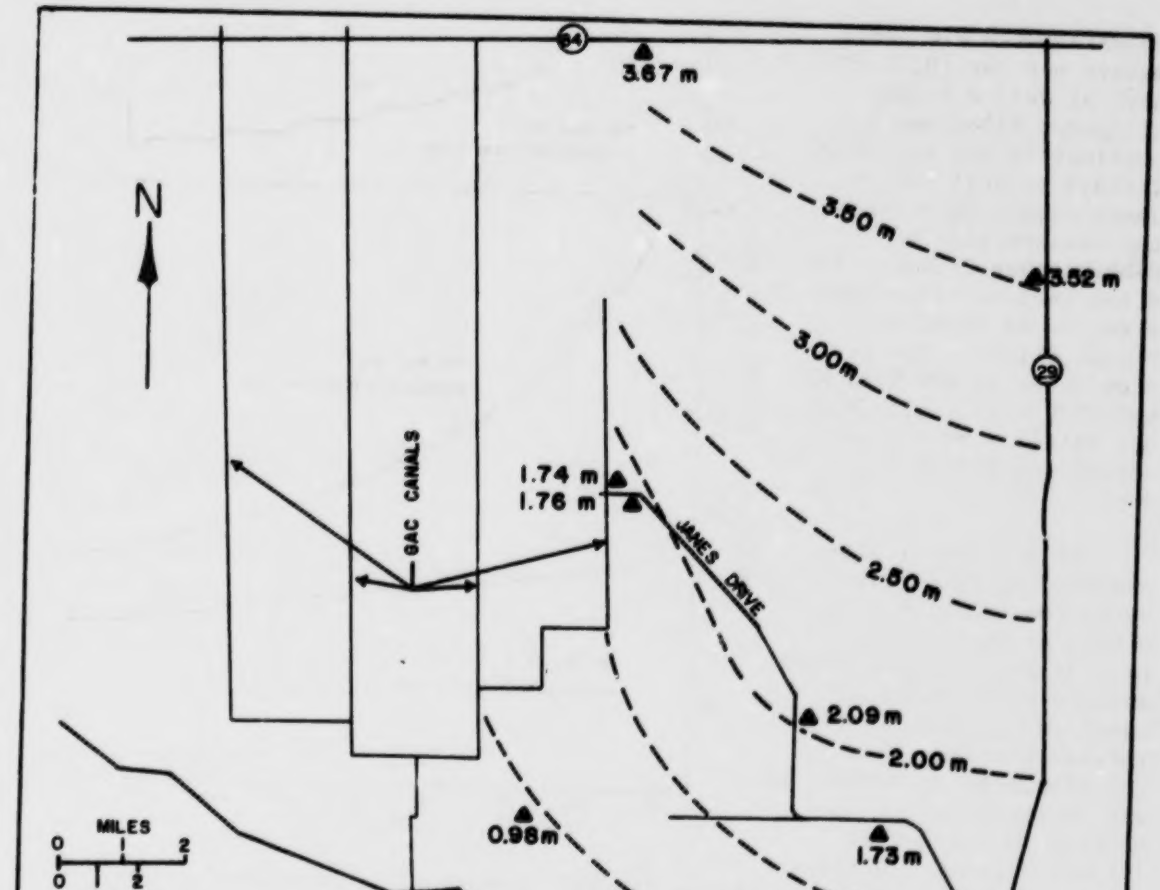

84
3.67 m
N
3.50 m
3.52 m
3.00 m
29
GAC CANALS
1.74 m
1.76 m
JANES DRIVE
2.50 m
2.09 m
2.00 m
MILES
0
1
2
0
2
KILOMETERS
0.98 m
1.73 m
1.50 m
COPELAND
FAHKA UNION CANAL
BIG CYPRESS BEND
1.00 m
41
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS
EXPLANATION
▲ Observed ground water levels on October 10, 1972

Figure VII-22. Ground water levels in Fahkahatchee Strand on October 10, 1972.

compares with 4.0 centimeters per day (0.13 ft/day) at Well W-1 near Alligator Alley and 2.1 centimeters per day (0.07 ft/day) at Well W-4 on Janes Scenic Drive near the eastern side of Fahkahatchee Strand. The rates include evapotranspiration as shown by Figure VII-23. The recession rates at EPA Well W-5 and USGS Well C-496 (Figure VII-1) were 2.1 centimeters per day (0.7 ft/day).

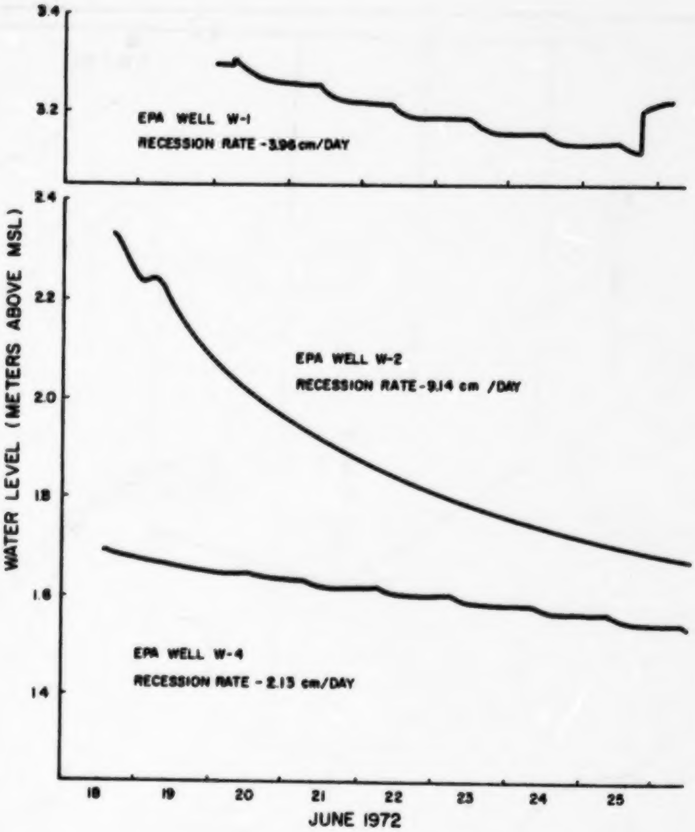


Figure VII-23. Ground Water Recession at EPA Wells W-1, W-2 and W-4.

As previously discussed, GAC Properties began construction of a bridge at the intersection of Janes Scenic Drive and the easternmost GAC canal on October 24, 1972. Initial pumping began on the afternoon of October 24 and continued until the morning of October 26 (Figure VII-24). During this period the pumping operations lowered the water level at W-2 by 0.61 meter per day (2.00 ft) and W-3 by 0.14 meter per day (0.45 ft). Upon cessation of pumping, the ground water level rapidly returned to near "normal" level. The maximum recession rate at W-2 was approximately 5.21 meters per day (17.1 ft/day for 1.8 hours) compared with 0.20 meter per day (0.67 ft/day) at W-3. Maximum recovery rate was 4.08 meters per day (13.4 ft/day) at W-2 and 0.26 meter per day (0.84 ft/day) at W-3. Conceivably, if pumping had continued for several weeks the ground water level at W-2 would approach the 1.54 meters (5.06 ft) below MSL in the pumping sump. This is evidenced by the second pumping period which began at approximately 8:00 a.m. on October 27 and continued until 8:00 a.m. on October 31. During this period the maximum drawdown at W-2 was 1.34 meters (4.51 ft) and 0.22 meter (0.72 ft) at W-3. Again, the recovery rate was very rapid upon cessation of pumping. As observed in Figure VII-24 additional pumps were installed on October 28. Based on knowledge of water levels in the sump and at W-2 and W-3, the pumpage between October 27 and 31 would have an effect on ground water levels approximately 0.91 kilometer (3,000 ft) from the canal.

Direct measurements of ground water contribution to a selected section of the GAC canal system (Section A-C on Figure VII-1) were made throughout the year. These measurements were made only when there was no visible

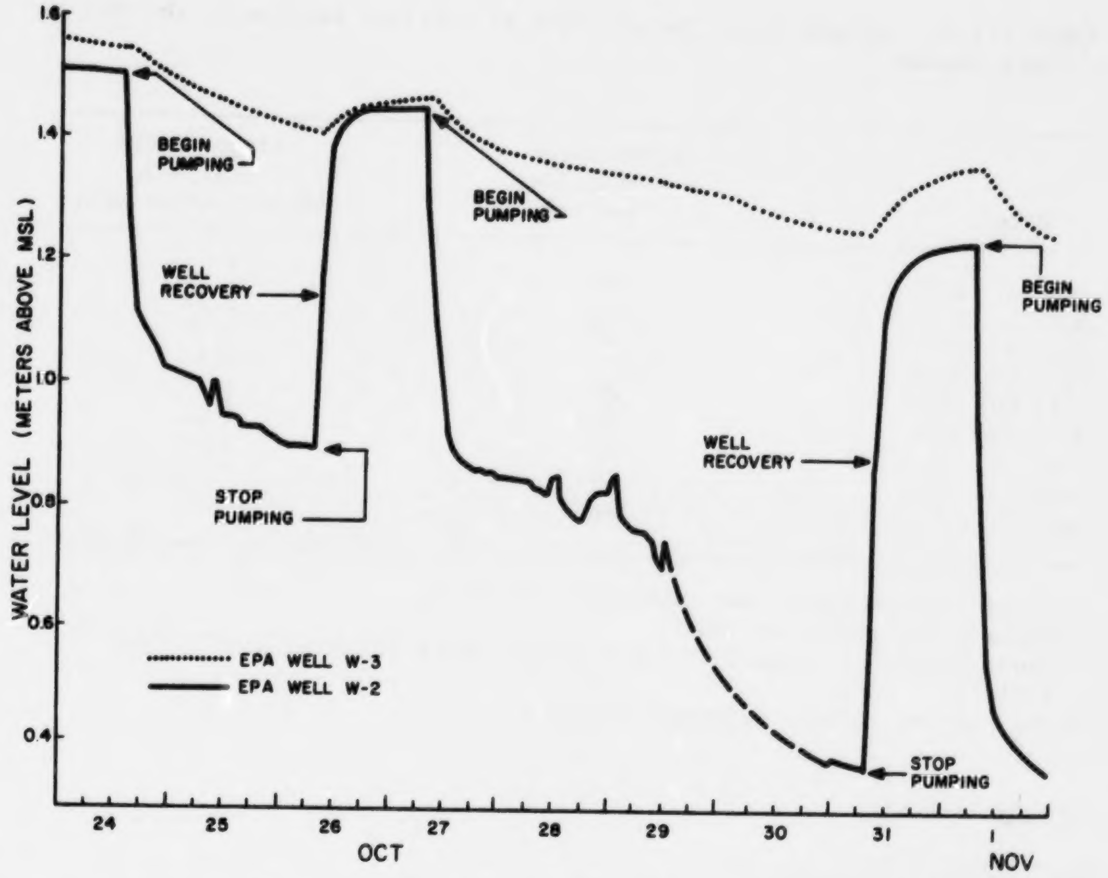


Figure VII-24. Effects of Pumpage on Ground Water Levels in the Vicinity of Janes Scenic Drive and the Easternmost GAC Canal.

surface water contribution to the canal. Table VII-1 is a summary of all measurements made during the study period.

The largest contribution of ground water occurred on October 8, 1971, at a rate of 558 l/sec/km (31.7 cfs/mi). However, the water level recorders had not yet been installed at the wells, and consequently, the stage is not known. Figure VIII-25 is a graphical representation of the increase in canal discharge per mile versus ground water stage at W-2. The mathematical equation of Q=297H-356 is based upon the four observations near the straight line where canal flow was unobstructed. The linear regression coefficient (R) is 0.96. Conceivably, it would be possible for water in the canal to recharge the ground water in time of droughts. However, for this to occur the water in the canal would have to originate from an external source in order for its stage to be higher than ground water stage. As observed from Figure VII-12, the stage at W-2 (near the canal) was always lower than W-3 (0.32 km {0.2 mile} away) during low stage periods, and consequently ground water recharge was non-existent. Only during periods of high canal flows following rapid surface runoff from adjacent areas was the stage higher at W-2 than W-3.

Table VII-1. Ground Water Contribution at a Select Section of the GAC Canal System.

Date	Ground Water Contribution (1/sec/km)	Stage at EPA Well W-2 (Meters Above MSL)
Oct. 8, 1971	558	a
Dec. 1, 1971	118	1.57
Jan. 4, 1972	95[b]	1.36
June 28, 1972	121	1.63
July 10, 1972	88	1.47
July 26, 1972	70[c]	1.63
Aug. 25, 1972	49[c]	1.46
Sept. 9, 1972	58	1.42
Nov. 2, 1972	186	0.34[d]

a Water level recorder not installed this date.
b Dense algae growth in canal.
c Canal partially blocked at Janes Scenic Drive (Station A on Figure VIII-1).
d GAC pumping in sump adjacent to well.

ESTUARY HYDROLOGY

Groundwater Input

Subsurface flow from Fahkahatchee Strand into the estuary below is extremely small. The hydraulic gradient of the ground water table from Janes Scenic Drive to the Gulf of Mexico was on the order of 0.001 m/m (0.0001 ft/ft) or 9.47 cm/km (0.5 ft/mi) during 1972. To obtain an approximation of this subsurface flow the general hydraulic equation Q = TIL was used.

Where:
Q = Flow in liters per day
T = Transmissibility of the aquifer in cm/sec
I = Hydraulic gradient in m/m
L = Length of the flow section in meters taken perpendicular to the direction of flow

A transmissibility value (T) of 4.3 cm/sec (92,000 gpd/ft) was used. This value was discussed previously in the groundwater section and is considered typical of the area in question.

Several parameters are not included in this approximation of subsurface flow. Canal drainage, storage, artesian flows, variations in hydraulic gradient and in transmissibility were not determined. However, the approximations should indicate an order of magnitude of the flows.

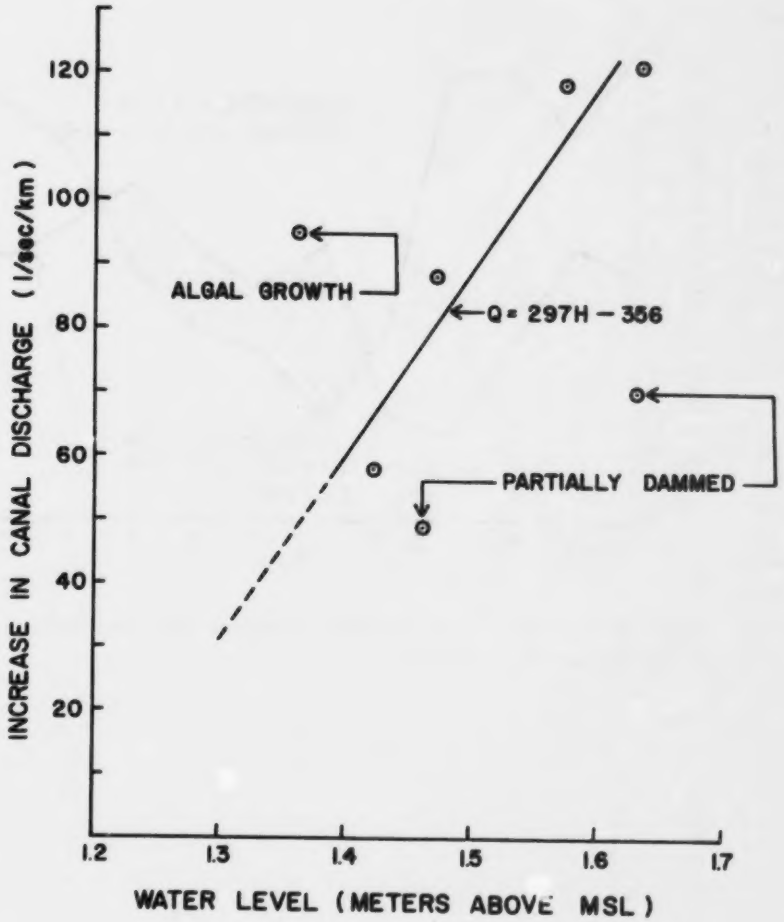


Figure VII-25. Increase in Discharge Due to Ground Water Infiltration in the Easternmost GAC Canal.

Two sections perpendicular to the north-south direction of flow were used. These sections are shown on Figure VII-1. The first section to intercept the north-south flow is US 41 from SR 29 westerly 16 kilometers (10 miles). The second (estuary) section is parallel to and of the same approximate length as the US 41 section. This section is at the northern general edge of Fahkahatchee Bay. The hydraulic gradient for the subsurface flow passing the US 41 section was determined by use of USGS Well C-496 on Janes Scenic Drive and EPA Well W-5 north of Remuda Ranch. The gradients were adjusted to the direction of flow. The hydraulic gradient for the estuary section was determined by Well W-5 and the average water elevations in Fahkahatchee Bay.

Figure VII-26 is a plot of monthly subsurface flow in cubic meters for the two sections. Subsurface flow passing US 41 ranged from 140,060 m^3/mo (37 million gal/mo) for January 1972 to 30,283 m^3/mo (8 mgpm) for June 1972 with an average value of 95,392 m^3/mo (25.2 mgpm). Flow passing into the estuary ranged from 100,313 m^3/mo (26.5 mgpm) for September 1972 to 25,741 m^3/mo (6.8 mgpm) for April 1972 with an average of 70,303 m^3/mo (18.5 mgpm). As shown on this figure the flow passing into the estuary exceeded the flow passing U.S. 41 from mid-May through mid-September.

For the period of mid-May through early September the monthly rainfalls exceeded the pan evaporation, thus, accounting for the increase in flows (Figure VII-21). However, for the year (1972) only 75 percent of the subsurface flow passing U.S. 41 reaches the estuary. Again, this is due in large part to the imbalances of evaporation-transpiration and rainfall.

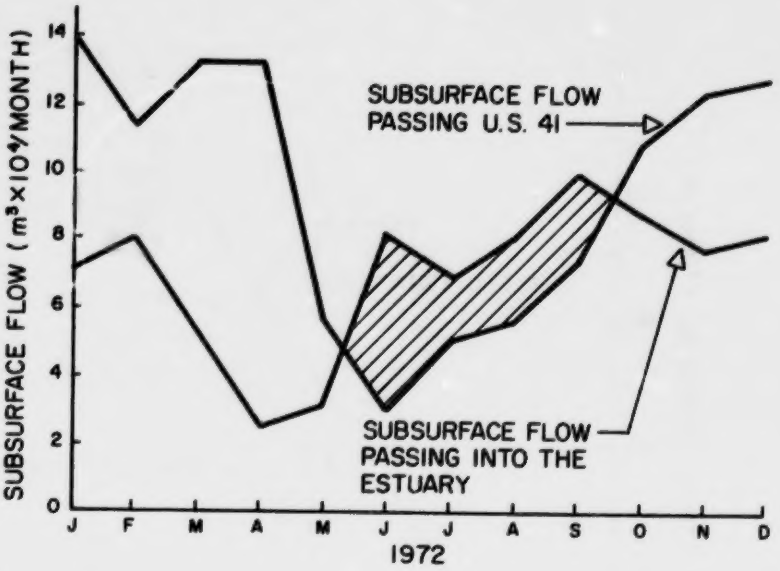


Figure VII-26. Subsurface Flow in the Southern End of Fahkahatchee Strand.

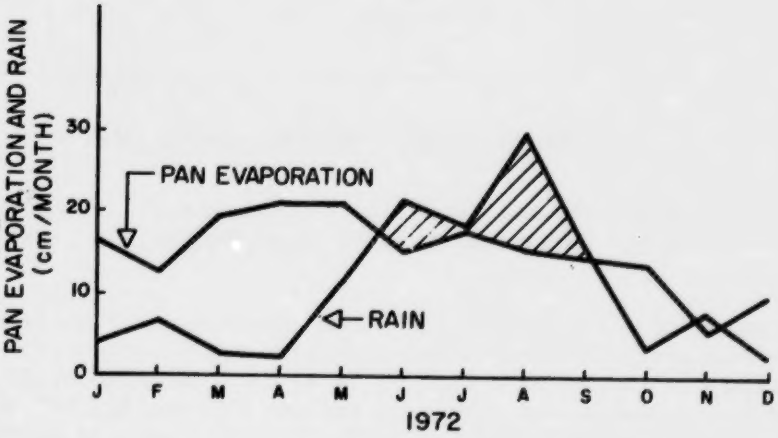


Figure VII-27. Pan Evaporation Versus Rainfall in Fahkahatchee Strand.

Table VII-2 shows the monthly magnitudes of flows passing the two sections discussed above and also the drainage canal system bordering the western end of the Strand. The column marked "Canal Drainage" is the monthly averages of the ground water flow into a 1.6 kilometer (one mile) stretch of the easternmost GAC canal near its intersection with Janes Scenic Drive. The values shown in this column are for 50 percent of the ground water interception, assuming that the ground water inflow to this canal section comes equally from the east and from the west. It should be emphasized that column 4 is for only a 1.6 kilometer (1 mi) section of the canal. Since this section is at the western edge of one of the "wettest"

Table VII-2. Ground Water Flows in $m^3 \times 10^3$ Per Month.

Month	Subsurface Flow Passing US 41	Subsurface Flow Passing into the Estuary	Canal[a] Drainage	Fahka-Union Canal
Dec., 1971			508	
Jan., 1972	137	72	-	1,888
Feb.	114	80	-	5,736
Mar.	133	51	-	2,235
Apr.	132	25	-	699
May	56	31	-	4,213
June	29	83	504	35,309
July	50	69	367	24,220
Aug.	56	81	-	22,434
Sept.	74	100	242	30,335
Oct.	108	88	-	25,142
Nov.	124	77	776	15,098
Dec.	128	83	-	9,954
Total[b]	1,114	840		177,263

[a] Flows into 1.609 kilometers (one mile) section of GAC Canal near Janes Scenic Drive. Incomplete due to construction during a portion of the year.

[b] Totals are for 1972.

portions of the GAC properties in Collier County no attempt was made to extrapolate to the entire drainage system estimated at 305.7 kilometers (190 mi). However, it is evident from Table VII-2 that ground water interception by a 1.6 kilometer (1 mi) section of a north-south drainage canal is approximately six times greater than the "normal" ground water input to the estuaries from a 16 kilometer (10 mi) east-west section. The final column is monthly flows passing the weir on Fahka Union Canal at its intersection with US 41. This canal is fed by the vast GAC drainage system. These flows give an indication of the relative water inputs to the esturarine system.

Estuary Bathymetry

Introduction

Soundings were made in both bays in order to: (1) make topographic comparisons of the bays, (2) obtain volume, area and mean depth relationships to tidal stages. From these finding numerous applications will be made throughout the report such as circulation patterns, turnover rates, water column depths, and sediment accumulations to name a few.

Methods

A Bludworth Marine Portable Echo Sounding Survey Recorder, Model ES-130AVF, was used in mapping bay topography and obtaining channel cross sections whenever needed. The bathymetry study consisted of 99 transects totaling 33.0 kilometers (20.5 mi) in Fahka Union Bay and 93 transects totaling 40.2 kilometers (25 mi) in Fahkahatchee Bay.

A Stevens Type A, Model 71, Continuous Stage Recorder was mounted in Fahkahatchee Bay. Since no bench marks were available, the datum was approximated by comparing mean daily and flood tide levels with records from two stage recorders located at Rookery Bay near Marco Island. These Rookery Bay recorders were previously referred to MSL (1929 datum). Selected days were used when wind action was negligible and tidal patterns were regular during the spring tide period. The estimated datum should be accurate within ±3.0 centimeters (0.1 ft).

Results

Both Fahkahatchee and Fahka Union Bays are classified as shallow inland bays. The bays are characteristically shallow in the northern half averaging 0.6 - 0.9 meter (2 - 3 ft) in Fahka Union Bay (Figure VII-28) and 0.9 - 1.2 meters (3 - 4 ft) in Fahkahatchee Bay (Figure VII-29). The average depth increases by approximately 0.30 meter (1.0 ft) in the southern half of each bay.

The average depth of Fahkahatchee Bay is 1.18 meters (3.88 ft) compared to 0.93 meter (3.06 ft) in Fahka Union Bay. Ninety percent of Fahkahatchee Bay has a depth greater than 0.82 meter (2.70 ft) compared to 0.75 meter (2.45 ft) in Fahka Union Bay (Figures VII-30 and 31).

At MSL Fahka Union Bay has a surface area of 186 hectares (460 ac) and a volume of 1,800,000 cubic meters (1,459 ac-ft) (Figure VII-32). At approximately 0.61 meter (2.0 ft) above MSL the majority of the islands become inundated and the surface area increased to 200 hectares (494 ac) with a box volume of 2,950,000 cubic meters (2,351 ac-ft). When the low ebb decreases to 0.61 meter (2.0 ft) below MSL the inundated portion of the bay is 164 hectares (405 ac). During the winter, a spring tide and a strong northerly wind decreases the inundated area to approximately 50 percent. At this condition the water level has fallen to some 0.81 meter (2.65 ft) below MSL and the volume decreased to 300,000 cubic meters (243 ac-ft).

At MSL Fahkahatchee Bay has a surface area of 740 hectares (1,829 ac) and a volume of 8,800,000 cubic meters (7,134 ac-ft) (Figure VII-33). At 0.61 meter (2.0 ft) above MSL the surface area increased to 765 hectares (1,890 ac) with a volume of 13,300,000 cubic meters (10,782 ac-ft). Some 680 hectares (1,680 ac) are inundated at 0.61 meter (2.0 ft) below MSL.

Circulation Patterns

Introduction

Fahkahatchee and Fahka Union Bays are shallow bodies of water with average depths at MSL of 1.18 meters and 0.93 meter, respectively. The bays

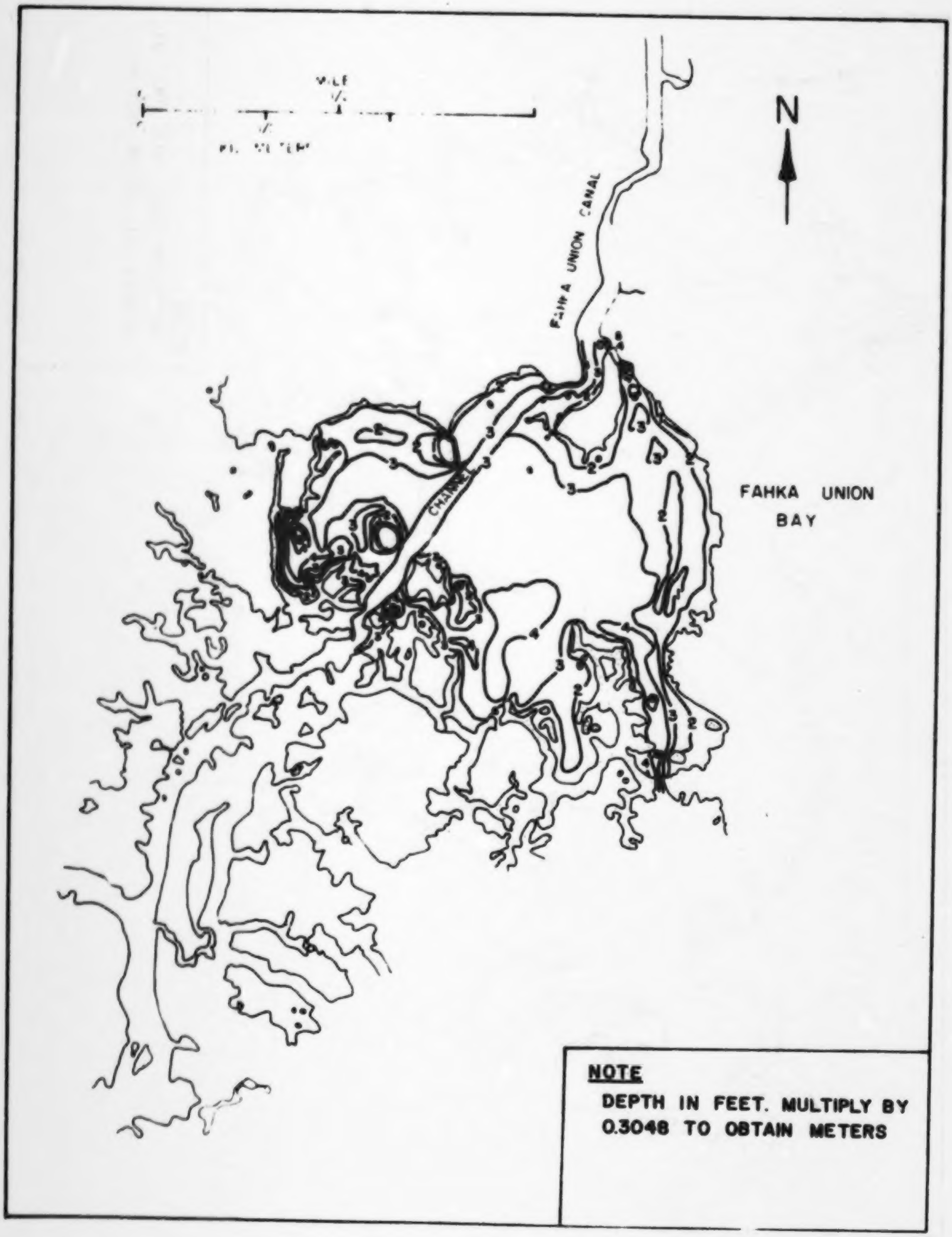

0
MILE
1/2
1/2
KILOMETER
N
FAHKA UNION CANAL
CHANNEL
FAHKA UNION
BAY
2
3
4
NOTE
DEPTH IN FEET. MULTIPLY BY
0.3048 TO OBTAIN METERS

Figure VII-28. Fahka Union Bay Showing Major Bathymetric Features.

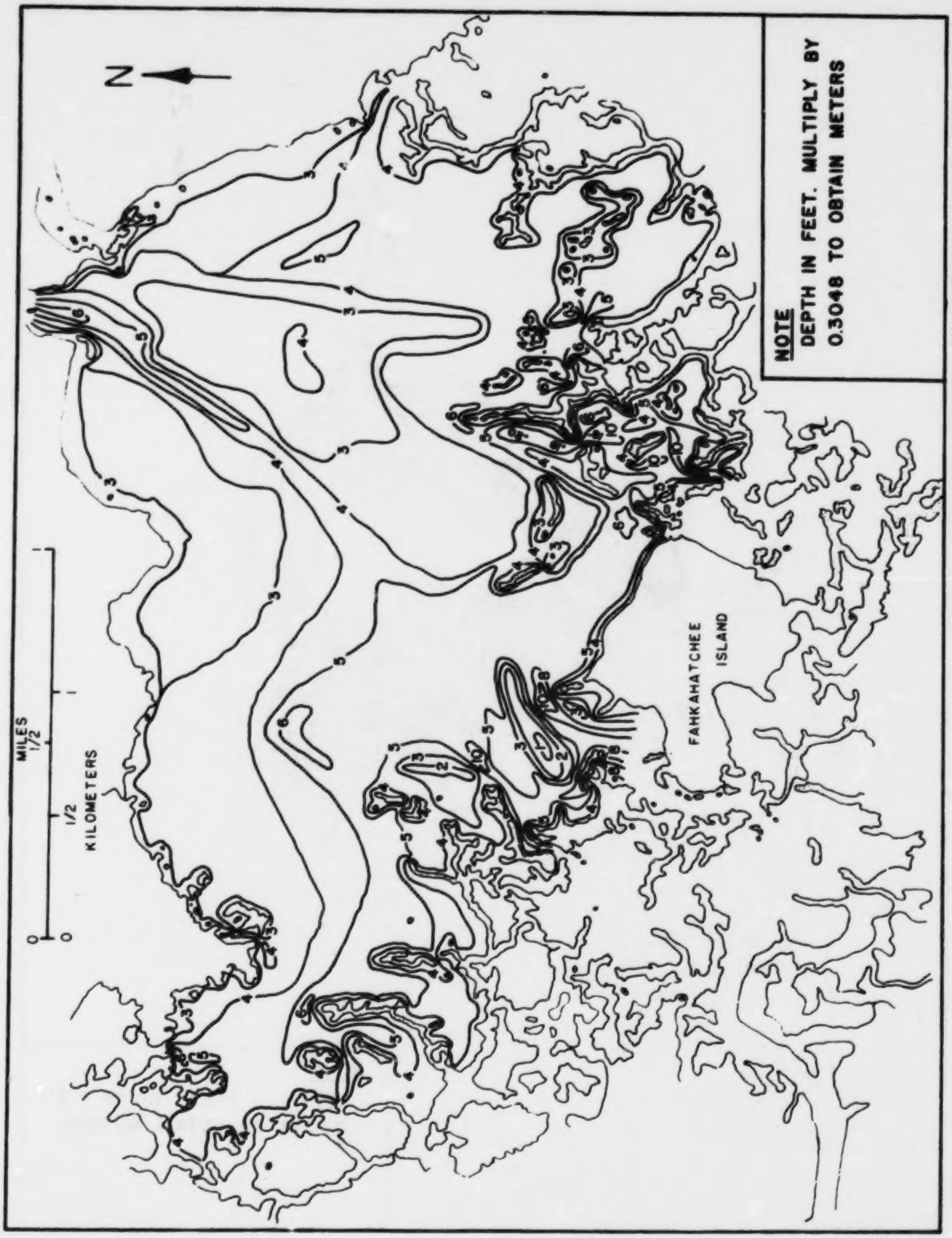

N
MILES
0
1/2
0
1/2
KILOMETERS
FAHKAHATCHEE ISLAND
NOTE
DEPTH IN FEET. MULTIPLY BY 0.3048 TO OBTAIN METERS

Figure VII-29. Fahkahatchee Bay Showing Major Bathymetric Features.

are characterized by muddy bottoms occasionally relieved by a more sandy bottom or by oyster bars. To the north the bays are bordered by mangrove flats and tidal creeks which blend into brackish tidal marshes further inland. Due to extreme flatness, much of the area to the north becomes inundated during flood tides making boundaries for the bays non-delineable. The southern extreme of the bays are separated from the Gulf of Mexico by the "Ten Thousand Island" chain. Numerous passes meander through these islands allowing circulation between the bays and outer keys. Many of these passes are six to eight meters in depth with well scoured sandy bottoms.

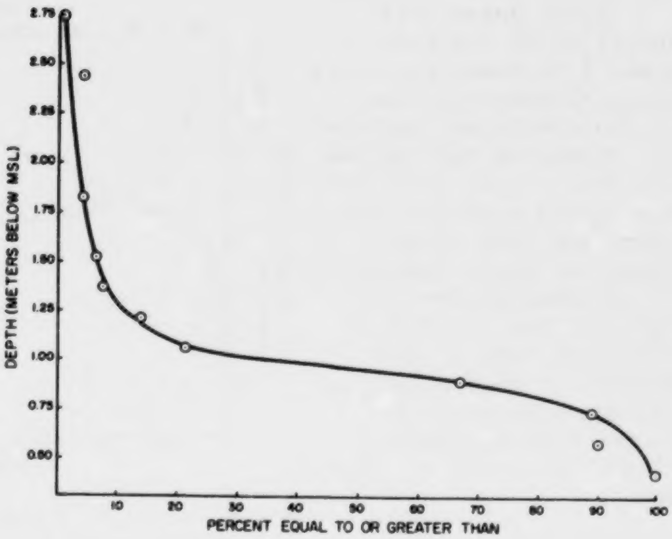


Figure VII-30. Depth Patterns in Fahka Union Bay at MSL.

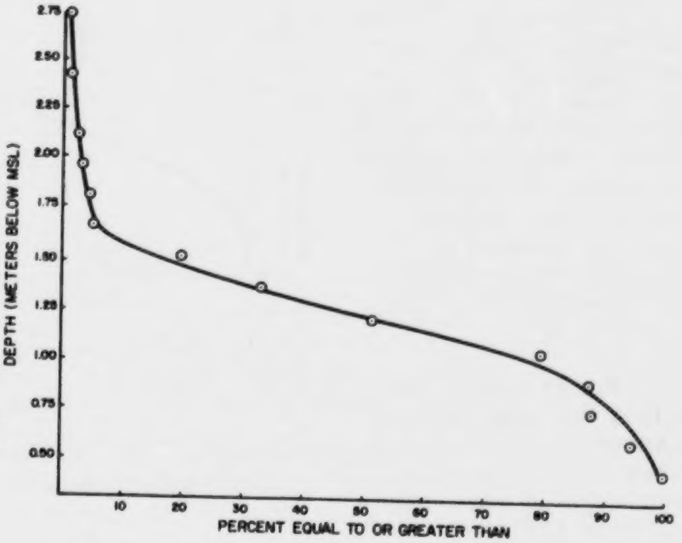


Figure VII-31. Depth Patterns in Fahkahatchee Bay at MSL.

Methods

A circulation study of Fahkahatchee Bay was conducted on October 5 and 6, 1972. This was a joint study with the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences. The purpose of the study was to: (1) quantify the water movement between Fahkahatchee Bay and the various openings to the uplands and the Gulf of Mexico; (2) determine the exchange of flows between Fahkahatchee Bay and adjacent bays; and (3) determine the tidal prism and flushing rate of Fahkahatchee Bay.

The study consisted of utilizing two two-man sampling teams each equipped with a sixteen foot boat, Beckman RS5-3 Salinometer, Bendix ducted current meter and sample bottles for laboratory salinity check. The location of the eleven sampling stations and a Stevens Type A-71 Stage Recorder are shown in Figure VII-34.

Staff gages were installed at Stations 1, 2 and 5 in order to relate stage at sampling times to the continuous recorder. Sampling was carried out over a full tidal cycle during a period when there were two equal tides per day. Station 10 was sampled over two tidal cycles. A fathometer was used at each station so that relationships between sectional area and water elevations could be computed.

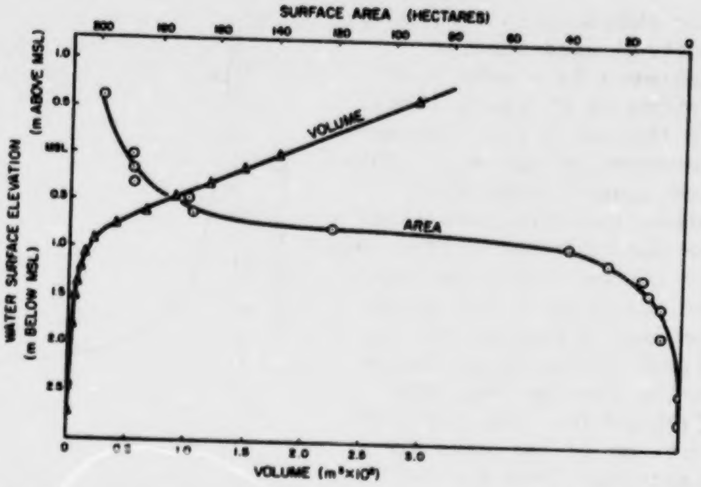


Figure VII-32. Volume, Area, Depth Relationship in Fahka Union Bay.

The eleven stations were divided between the two field parties with each party attempting to sample each of its stations hourly. Vertical salinity profiles were measured at 61 centimeters (2 ft) increments from 30 centimeters (1 ft) below the surface to 30 centimeters above the bottom. Surface salinity samples were intermittently checked by standard laboratory procedures.

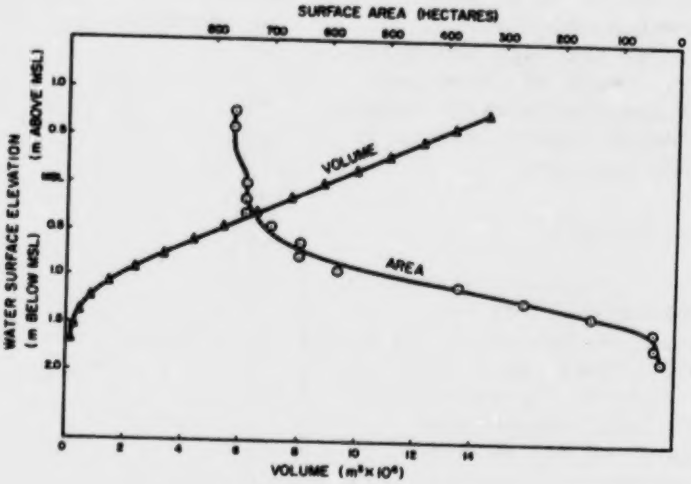


Figure VII-33. Volume, Area, Depth Relationship in Fahkahatchee Bay.

The following procedure was used at each station for calculating flows. Flows passing each station were computed from field measured velocity and cross sectional area relationships and tidal stage (Figure VII-35). Field measured velocity curves are shown in Figure VII-36. As seen by the velocity curve for Station 10, the transition between tides or slack time was typically a very short period. Flow curves, Figure VII-37, are then plotted against time and integrated for total volume passing a particular station over the required time period.

Results

Table VII-3 lists the flow delineations of each station as measured during this study. The percentages shown are relative to the total flow

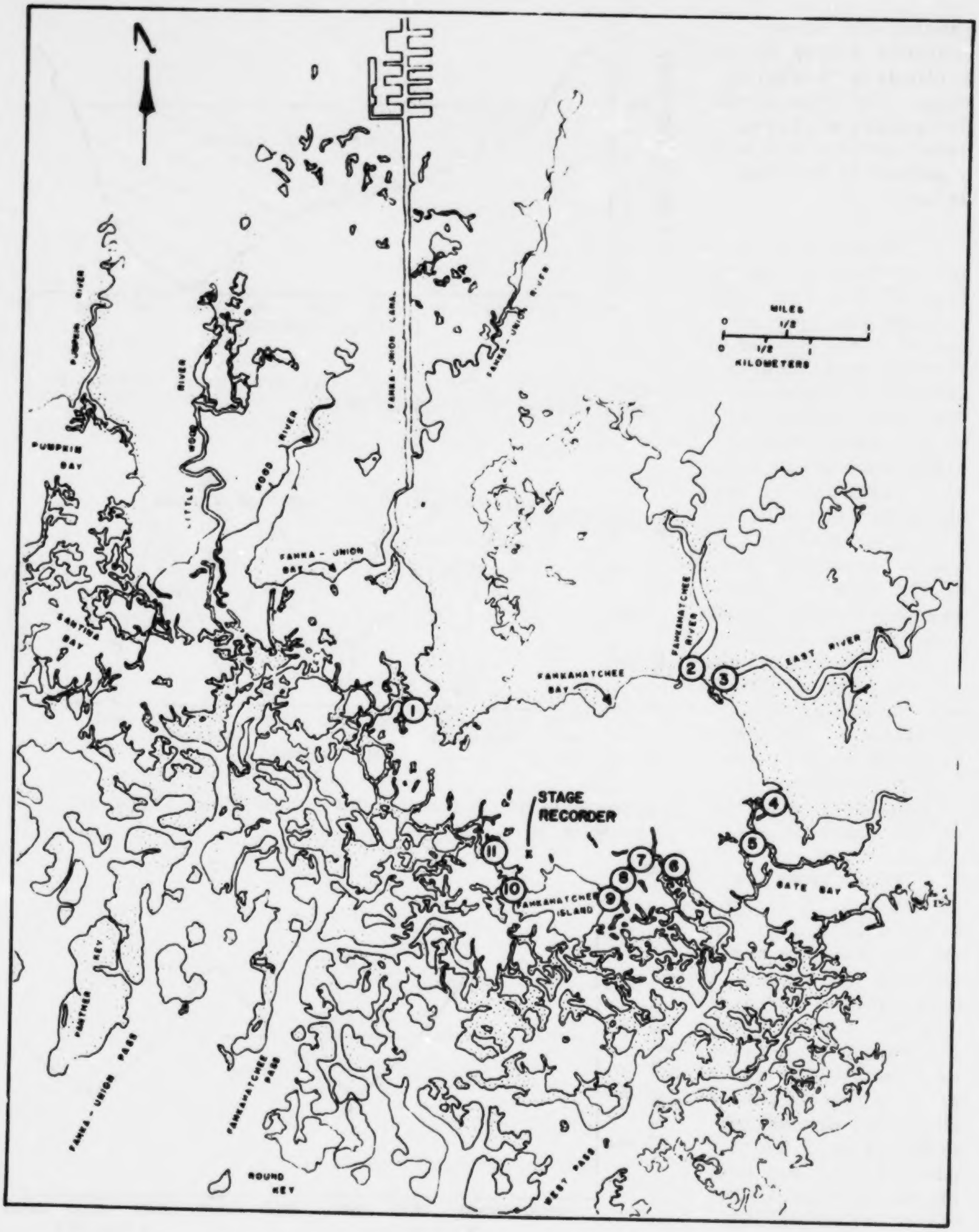

PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAKKA - UNION CANAL
FAKKA - UNION RIVER
FAKKA - UNION BAY
SANTINA BAY
MILES
0
1/2
1
0
1/2
1
KILOMETERS
FAKKAHATCHEE RIVER
EAST RIVER
FAKKAHATCHEE BAY
1
2
3
4
5
6
7
8
9
10
11
STAGE RECORDER
FAKKAHATCHEE ISLAND
GATE BAY
PANTHER KEY
FAKKA - UNION PASS
FAKKAHATCHEE PASS
ROUND KEY
WEST PASS

Figure VII-34. Map of Study Area Showing Flow Measurement Stations.

passing all eleven stations during either a flooding or ebbing tide. The term flood designates a rising water surface and ebb a period of falling water.

Figures VII-38 and 39 show the direction of flow for each station and percentage of total discharge passing a particular station relative to the total discharge of the eleven stations during one-half of a tidal cycle. As shown by Figure VII-38, during a flooding tide, approximately 80 percent of the total discharge was entering Fahkahatchee Bay via Stations 5 - 11 and 20 percent of the total discharge was departing via Stations 1 - 4. As observed from Figure VII-39, the reverse of the above was true on the ebb tide.

Fahka Union Bay to the west (through Station 1) accounts for two to five percent of the total Fahkahatchee Bay discharge. Gate Bay to the southwest exchanges flow via Station 5 at only one percent of the total discharge. Stations 2, 3 and 4 pass flow in and out of the salt marsh by way of tidal creeks. Discharge during this particular study through the creeks at these three stations

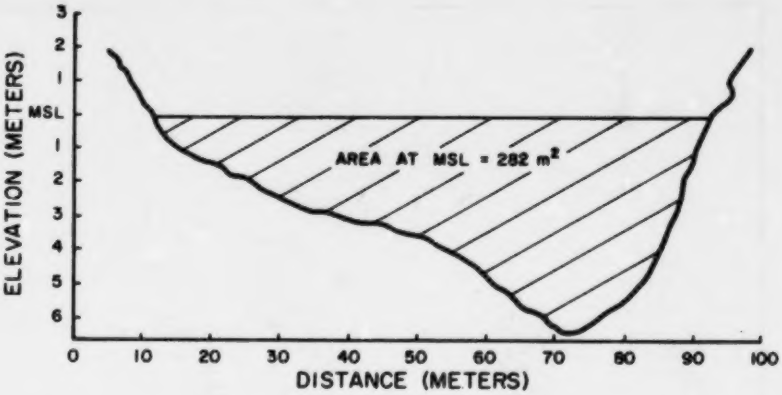


Figure VII-35. Cross Sectional Area Relationship to Tidal Stage at Station 10.

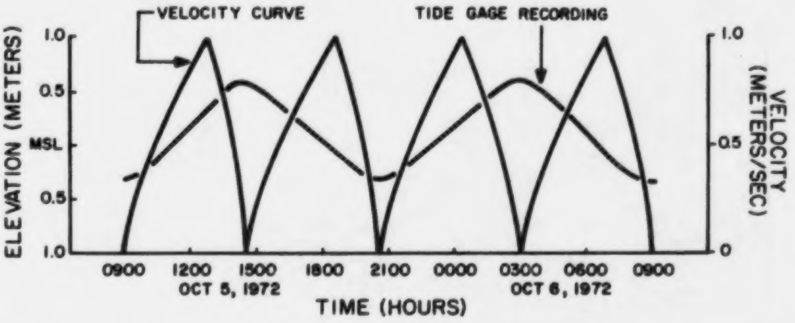


Figure VII-36. Velocity Curve and Tidal Stage at Station 10.

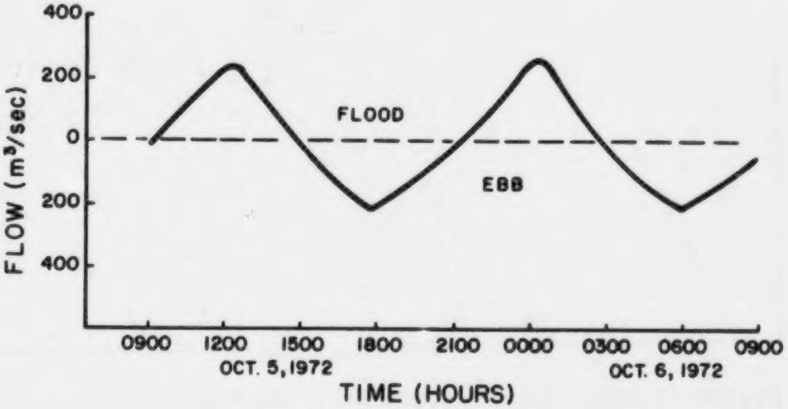


Figure VII-37. Flow Versus Time at Station 10.

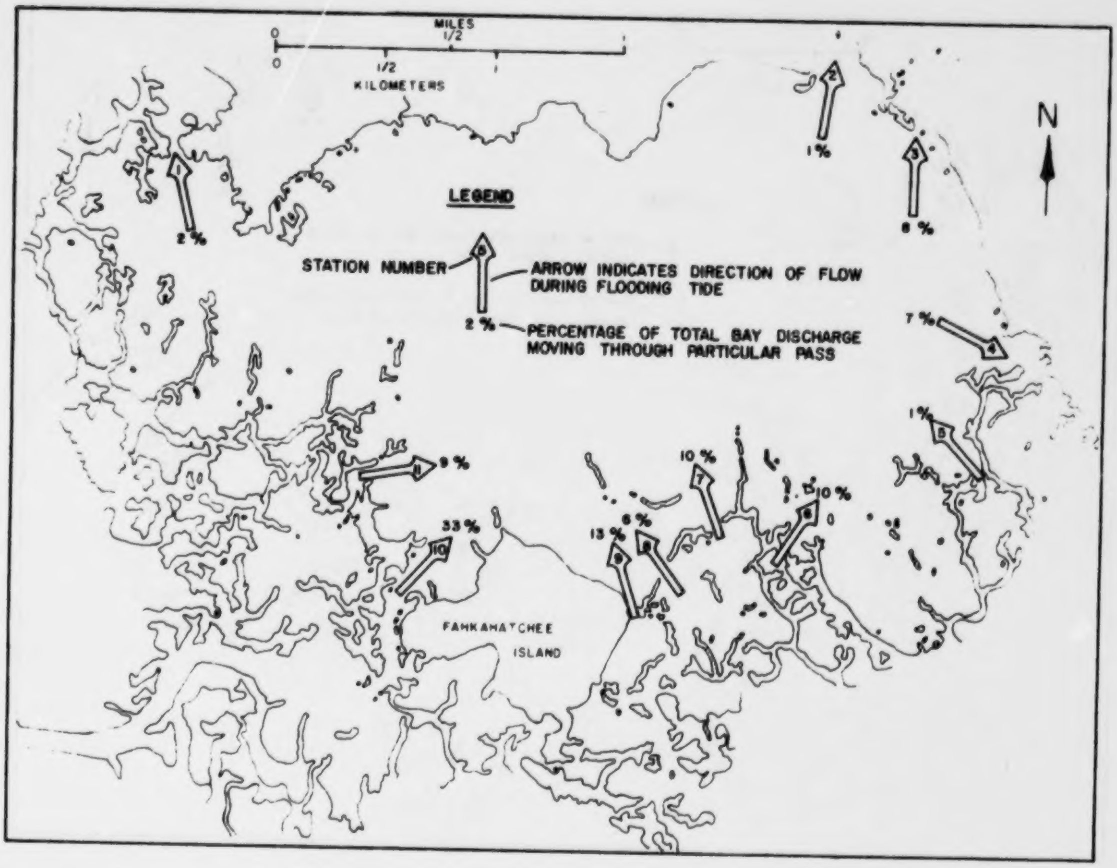

MILES
0
1/2
0
1/2
1
KILOMETERS
N
LEGEND
STATION NUMBER
ARROW INDICATES DIRECTION OF FLOW DURING FLOODING TIDE
2 %
PERCENTAGE OF TOTAL BAY DISCHARGE MOVING THROUGH PARTICULAR PASS
2 %
1 %
8 %
7 %
1 %
9 %
33 %
13 %
8 %
10 %
10 %
FAHKAHATCHEE ISLAND

Figure VII-38. Flow Directions and Percentage of Discharge in Fahkahatchee Bay During Flooding Tide, October 5-6, 1972.

accounted for 16 percent of the total discharge. These three stations are dependent not only upon stage and wind, but also upon other hydrologic conditions such as high runoff and droughts. Also evident is that the adjacent bays (Gate and Fahka Union) account for only three to six percent of the total discharge.

Water exits Fahkahatchee Bay through the passes during the ebb tide, mixes with offshore water and re-enters during the subsequent flood tide. Exchange ratio is the volume of "new" offshore water entering the bay divided by the total volume entering the bay during the flood tide. Parker (1972) developed the relationship with salinity as a tracer, where:

$$r = \frac{C_F - C_E}{C_O - C_E}$$

C_E = Weighted average salinity on ebb tide

C_F = Weighted average salinity on flood tide

C_O = Background salinity

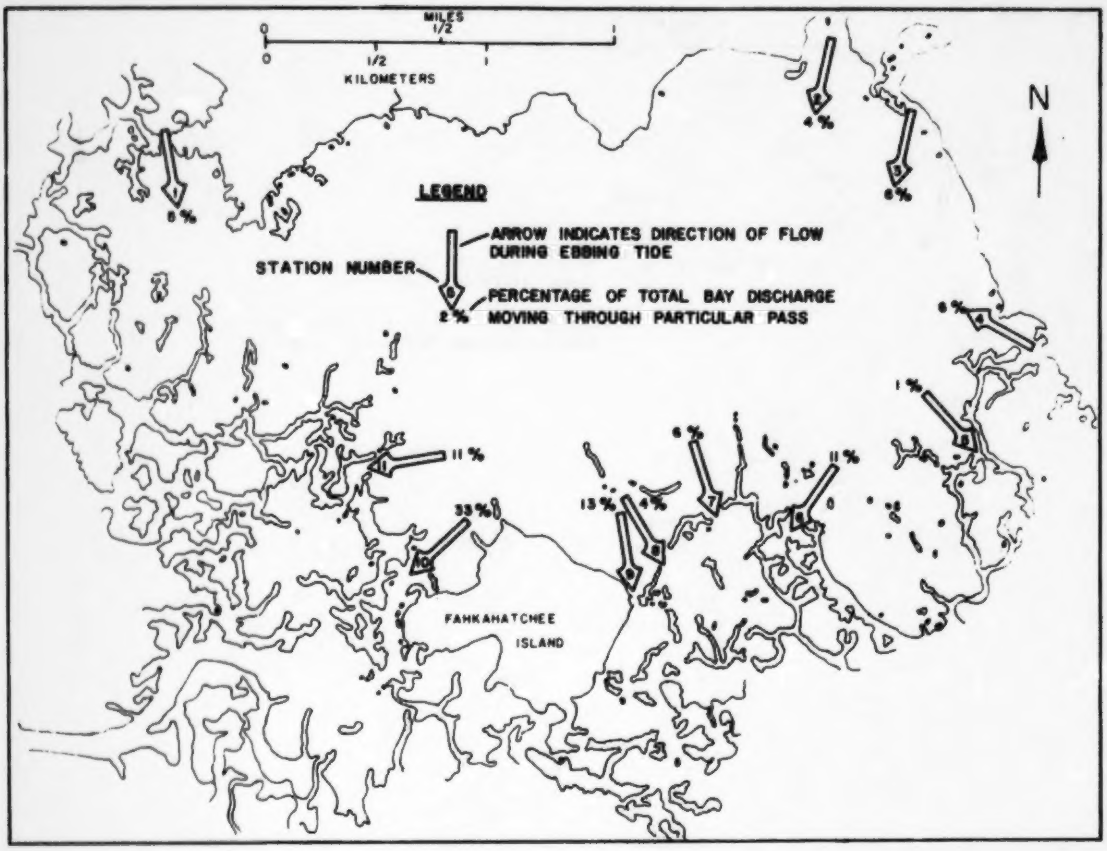

MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
LEGEND
ARROW INDICATES DIRECTION OF FLOW DURING EBBING TIDE
STATION NUMBER
PERCENTAGE OF TOTAL BAY DISCHARGE MOVING THROUGH PARTICULAR PASS
2%
5%
4%
6%
6%
1%
11%
6%
11%
33%
13%
4%
FAHKAHATCHEE
ISLAND

Figure VII-39. Flow Direction and Percentage of Discharge in Fahkahatchee Bay During Ebbing Tide, October 5 and 6, 1972.

Station 10 was monitored over two tidal cycles which produced sufficient data to arrive at a reasonable estimate for exchange ratio. Several offshore salinity measurements were made during the study. The general location of these samples were at Round Key, 8 and 4 kilometers (2.5 and 5.0 mi) seaward of Round Key. The "offshore salinities ranged from 27 to 34 ppt. Station 10 salinities (Figure VII-40 ranged from approximately 24 ppt to somewhat greater than 24 ppt.

Computation based on offshore salinities and Station 10 salinities yield a reasonable estimate of exchange ratio to be 10 percent. Therefore, on a flood tide approximately 10 percent of the water is "new" offshore water, and 90 percent has been in Fahkahatchee Bay or adjacent bays before. Assuming that the above ratio is typical of the other inlets, a flushing rate can be approximated.

Flushing rate in this case may be defined as the dilution of a given concentration by tidal action in a completely mixed system. This dilution, or decaying may be approximated by:

$$\frac{A_n}{A_o} = \{1 - (r\ TP/(V_{LW} + TP)\}^N$$

where: A_n = Concentration after N cycles
A_o = Initial concentration
V_{LW} = Bay volume at low water
TP = Tidal prism volume
N = Number of tidal cycles
r = Exchange ratio

High water and low water volumes were obtained from Figure VII-33. The tidal prism is the difference between low and high water volume. Figure VII-41 presents the calculated flushing rate in Fahkahatchee Bay assuming complete mixing and two tides of equal magnitude per day. As shown by this figure, a constituent would be reduced to 10 percent of the original concentration after 42 tidal cycles or approximately 21 days.

Seasonal variations affect tidal prism volumes, therefore, affecting flushing rates. Figure VII-42 was developed by applying monthly average tidal ranges to the flushing equation. The exchange ratio was held constant at 10 percent and the number of tidal cycles at 40. As observed on Figure VII-42, after 40 cycles in February, 8.5 percent of a given contaminant remains compared to 13 percent in August.

Table VII-3. Relative Discharge Per Station

Station Number	Flood % Q	Ebb % Q
1	2	5
2	1	4
3	8	6
4	7	6
5	1	1
6	10	11
7	10	6
8	6	4
9	13	13
10	33	33
11	9	11

Salinity and Temperature Variations

Introduction

An easily measurable parameter for assessing the physical effects of drainage on estuaries is differences in salinity patterns in areas subject to rapid, normal or below normal runoff. In general, Fahka Union Bay is subject to sporadic massive fresh water inputs from the GAC drainage system. In contrast, Fahkahatchee Bay receives normal or below normal runoff from the Fahkahatchee and East Rivers.

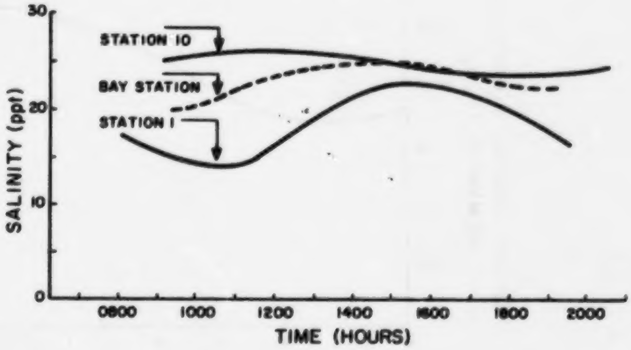


Figure VII-40. Salinity Curves for Stations 1, 10 and Mid-Bay, October 5, 1972.

Less than average runoff may occur in Fahkahatchee Bay due to the interception of surface and subsurface waters by the GAC canals to the west and the Barron River Canal to the east of Fahkahatchee Strand.

Salinity patterns in South Florida estuaries are generally very dynamic because of the seasonality of the hydroperiod. During winter drought periods the salinity in some estuaries increase above that of the Gulf of Mexico due to evaporation. Salinities exceeding 40 ppt have been measured in the Ten Thousand Islands area. During the summer, when rainfall and runoff is at a maximum, salinities at low ebb are often below 10 ppt.

For fish and other aquatic life to survive in the estuaries they must have a high salinity tolerance or be able to leave certain estuaries whenever the salinity becomes intolerable. Certain marine species migrate into the estuaries seeking optimum salinities and temperatures for reproductive purposes. Extreme variations in the normal spatial and temporal distribution

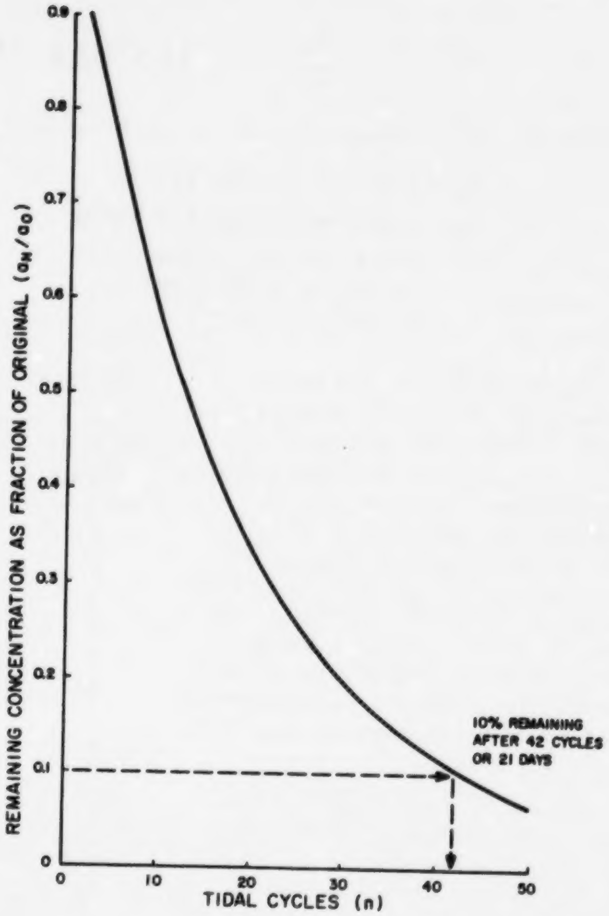


Figure VII-41. Dilution Curve for Fahkahatchee Bay. Fraction of Original Concentration Remaining Versus Tidal Cycles.

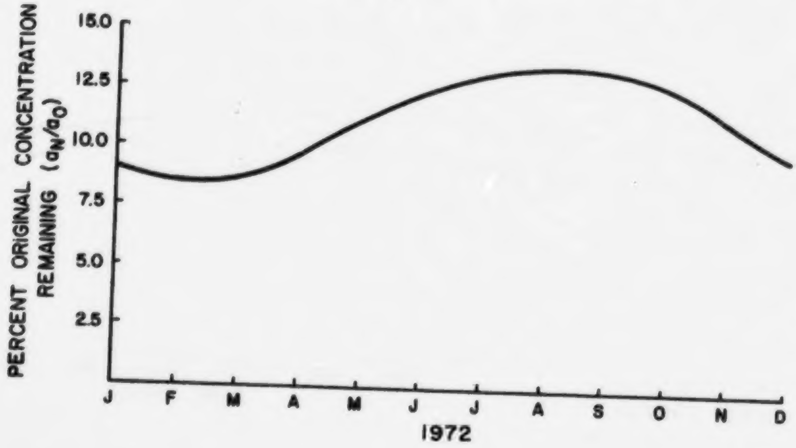


Figure VII-42. Monthly Average of Percent of a Given Contaminant Remaining in Fahkahatchee Bay After 40 Tidal Cycles.

of salinity may adversely affect the aquatic communities of an estuary. Some estuarine animals such as the blue crab and fiddler crab can live in or near water that is essentially fresh but must return to the ocean to spawn, since their eggs cannot develop in fresh water. Field studies of distribution show that the number of species decline as salinity falls, and the weight of physiological evidence strongly indicates that salinity is a limiting factor for marine organisms, especially when it varies downward (Pearse, 1957).

Methods

Data for salinity profiles of Fahkahatchee Bay, Fahka Union Bay, Fahka Union Pass, Fahkahatchee River, Fahkahatchee Pass and West Pass were collected every two months on both the high and low tides. Each study utilized two sampling crews. One crew concentrated in the bays and the other crew concentrated in the canals and passes. Studies were conducted from approximately 1.25 hours before to 1.25 hours after both the ebb and flood slack. Except as noted on the salinity profiles all measurements were made at the one foot depth using Beckman Model RS5-3 Portable Salinometers. Simultaneous temperature measurements were also conducted.

Results

Salinity station locations for the estuaries and canal-passes are shown in Figures VII-43 and 44. The bay study consisted of 55 stations (1 through 55) and the canal-passes 33 stations (56 through 88).

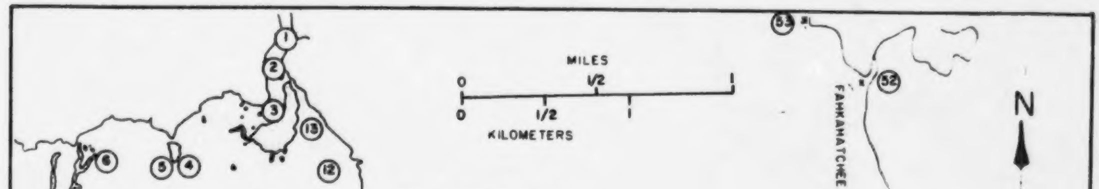


Figure VII-43. Map of Fahka Union and Fahkahatchee Bays Showing Station Locations for Estuary Salinity Studies.

Inflow to the bays was relatively low in January with a minimum occurring in April (Figures VII-45 through 56).

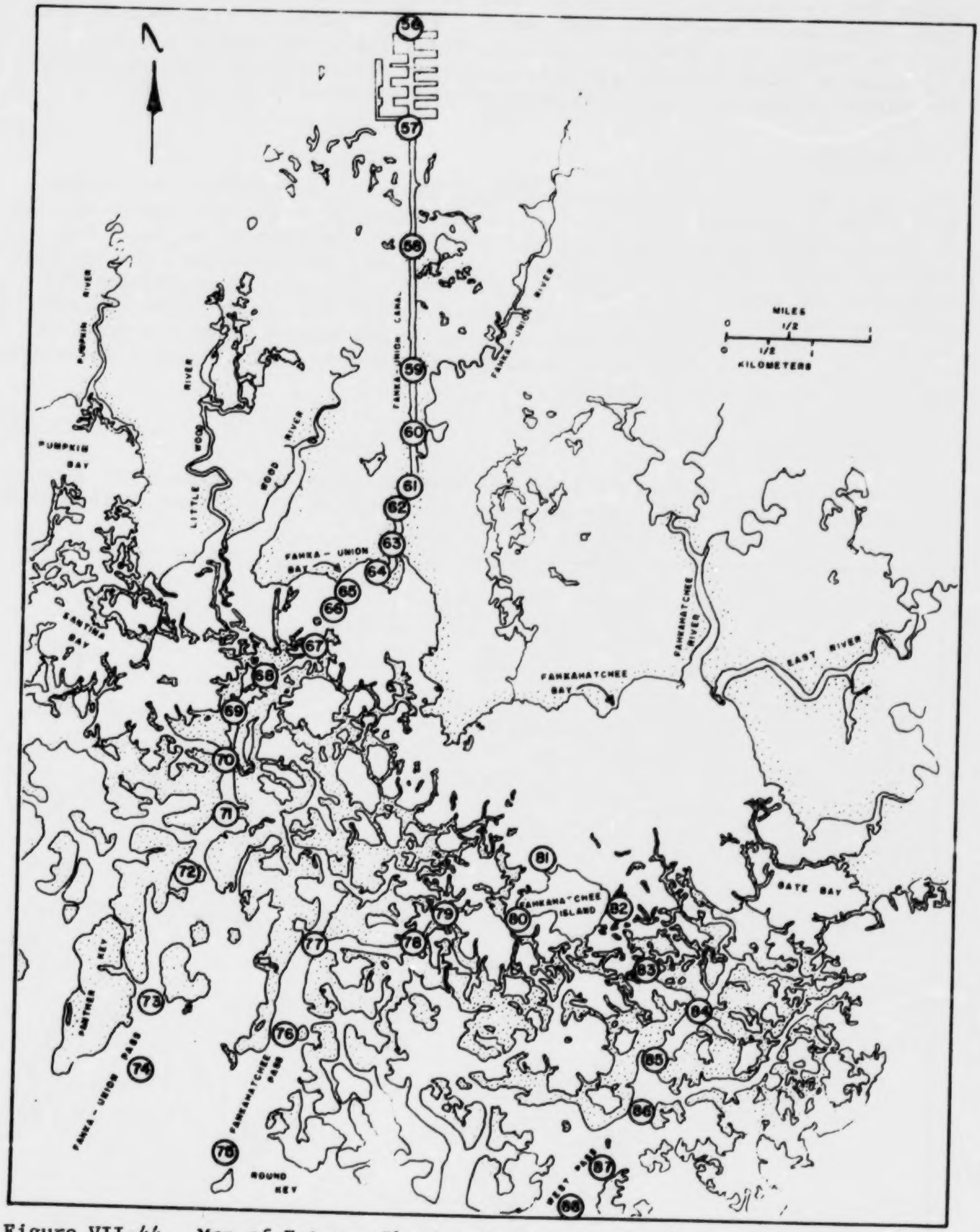

56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAKA - UNION CANAL
FAKA - UNION RIVER
FAKA - UNION BAY
EANTINA BAY
FAKAHATCHEE RIVER
FAKAHATCHEE BAY
EAST RIVER
GATE BAY
FAKAHATCHEE ISLAND
PANTHER KEY
FAKA - UNION PASS
FAKAHATCHEE PASS
ROUND KEY
WEST PASS
MILES
0
1/2
1
0
1/2
1
KILOMETERS

Figure VII-44. Map of Estuary Showing Station Locations for "Canal-Passes" Salinity Studies.

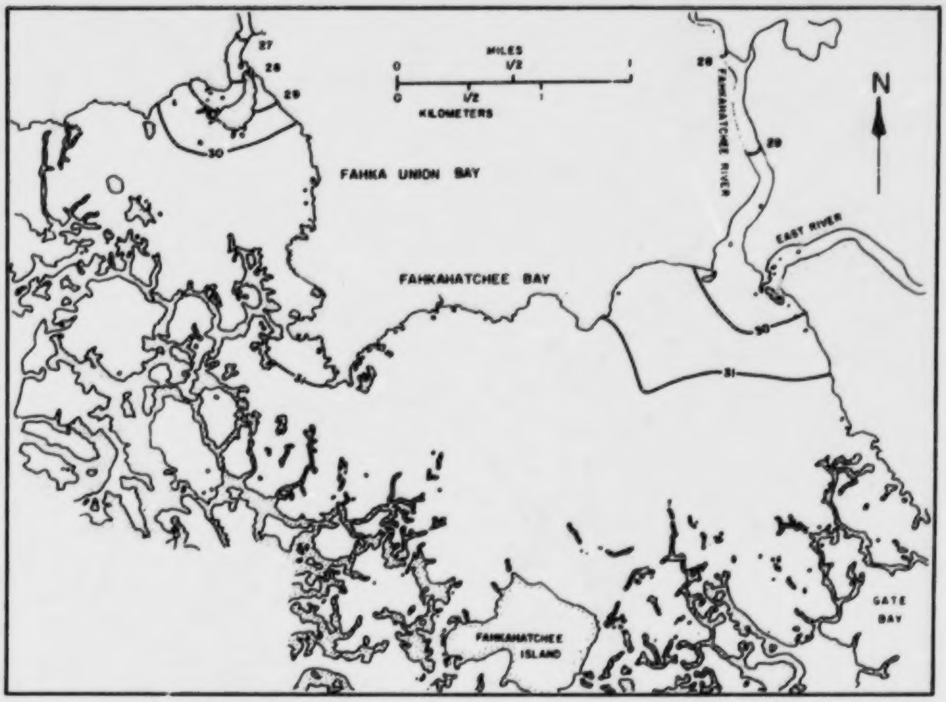

27
28
29
30
MILES
0
1/2
1
0
1/2
1
KILOMETERS
FAHKA UNION BAY
FAHKAHATCHEE BAY
28
FAHKAHATCHEE RIVER
29
EAST RIVER
30
31
N
GATE BAY
FAHKAHATCHEE ISLAND

Figure VII-45. Isohalines in Bays at Low Tide (a.m.) on Feb 1, 1972.

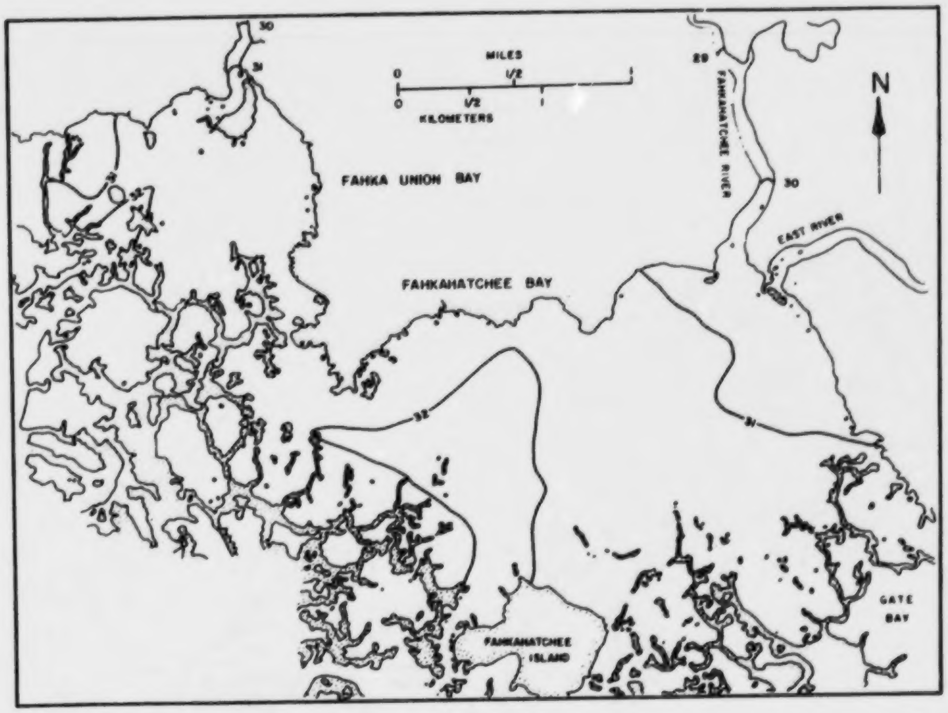

30
31
MILES
0
1/2
1
0
1/2
1
KILOMETERS
29
FAHKAHATCHEE RIVER
30
N
FAHKA UNION BAY
EAST RIVER
FAHKAHATCHEE BAY
32
31
GATE BAY
FAHKAHATCHEE ISLAND

Figure VII-46. Isohalines in Bays at High Tide (p.m.) on Feb 1, 1972.

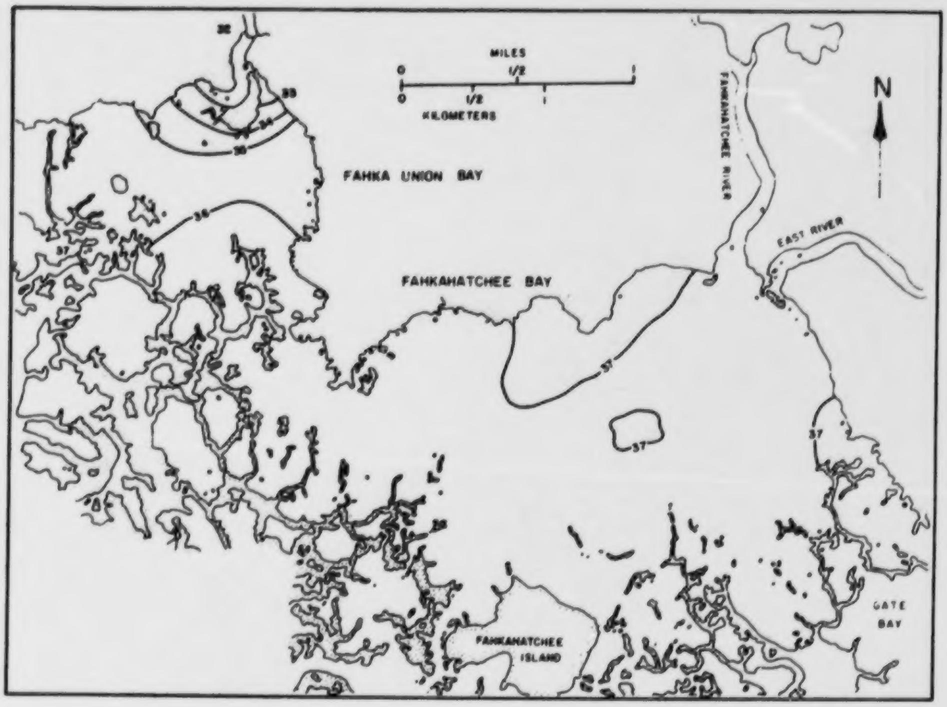

MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
37

Figure VII-47. Isohalines in Bays at High Tide (a.m.) on April 7, 1972

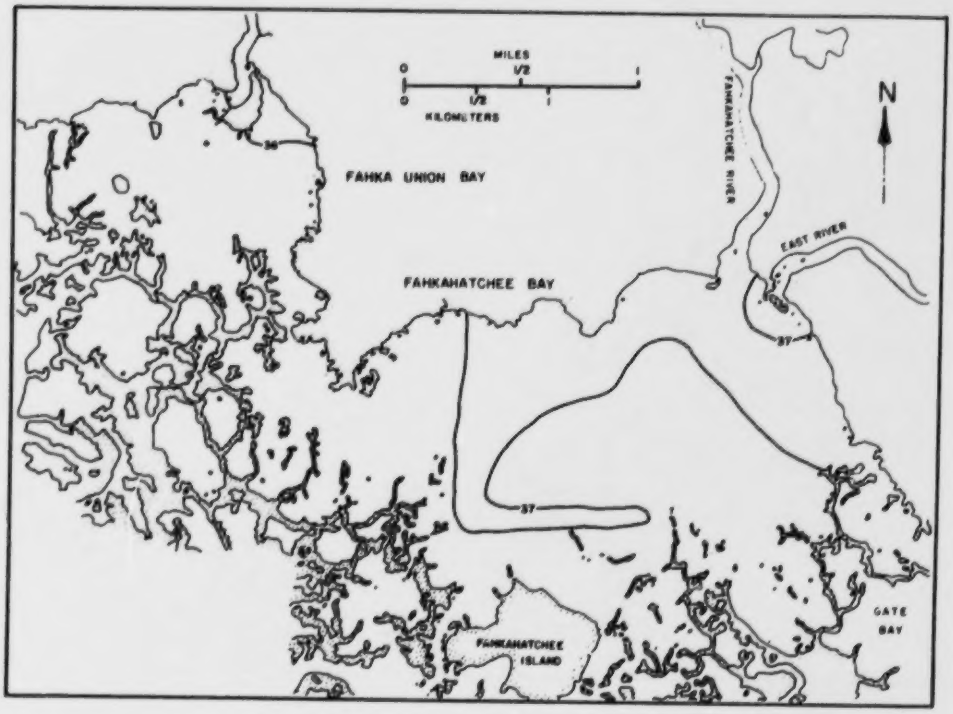

MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
37

Figure VII-48. Isohalines in Bays at Low Tide (p.m.) on April 7, 1972

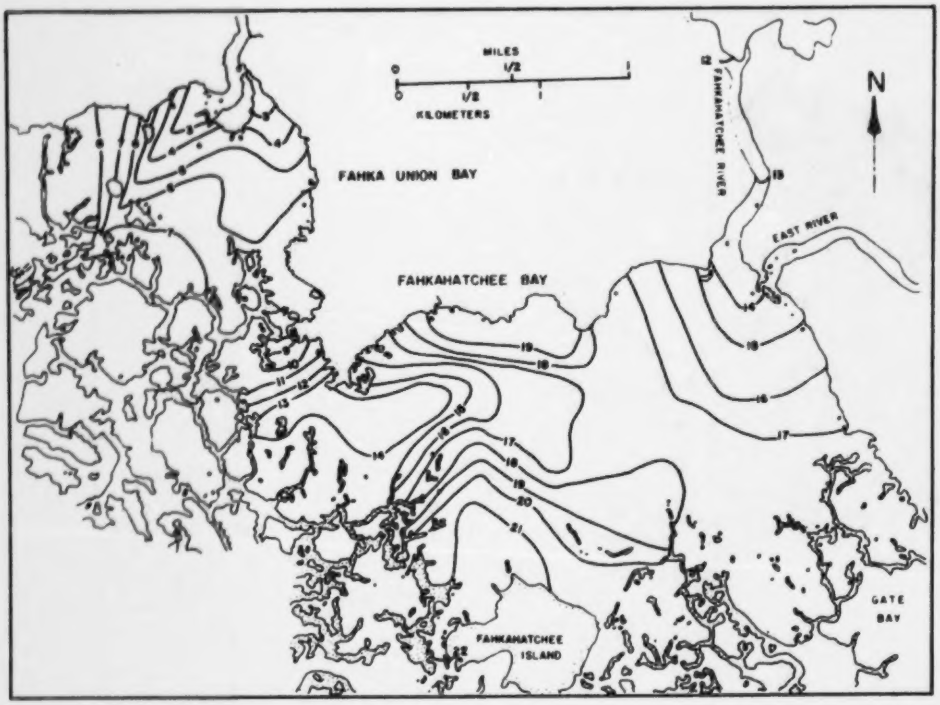

MILES
0
1/2
1
0
1/2
1
KILOMETERS
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
N
GATE BAY
FAHKAHATCHEE ISLAND

Figure VII-49. Isohalines in Bays at Low Tide (a.m.) on June 27, 1972.

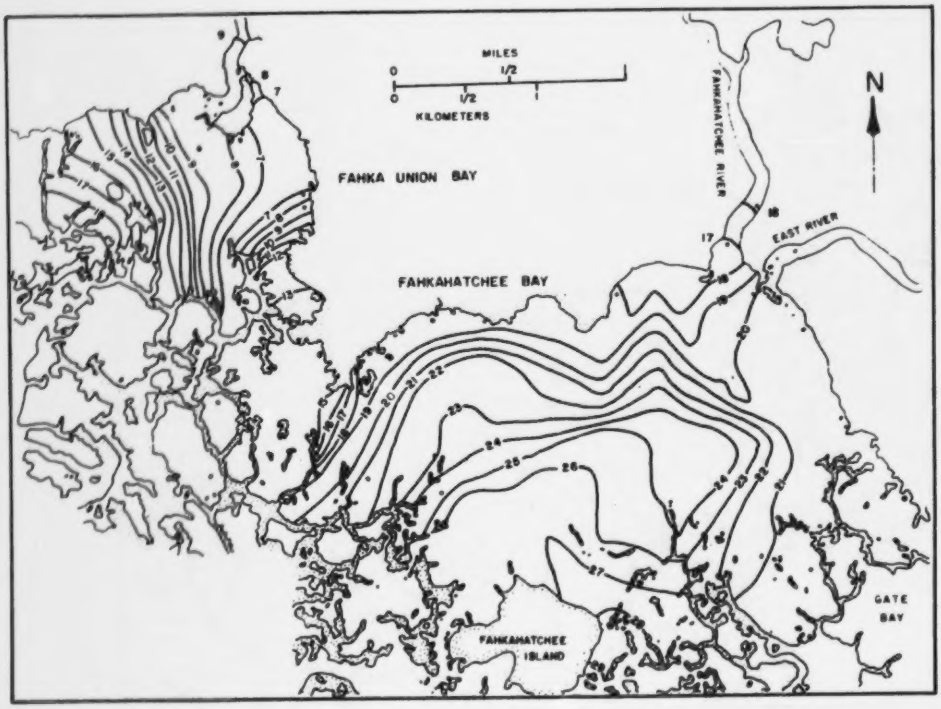

MILES
0
1/2
1
0
1/2
1
KILOMETERS
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
N
GATE BAY
FAHKAHATCHEE ISLAND

Figure VII-50. Isohalines in Bays at High Tide (p.m.) on June 27, 1972.

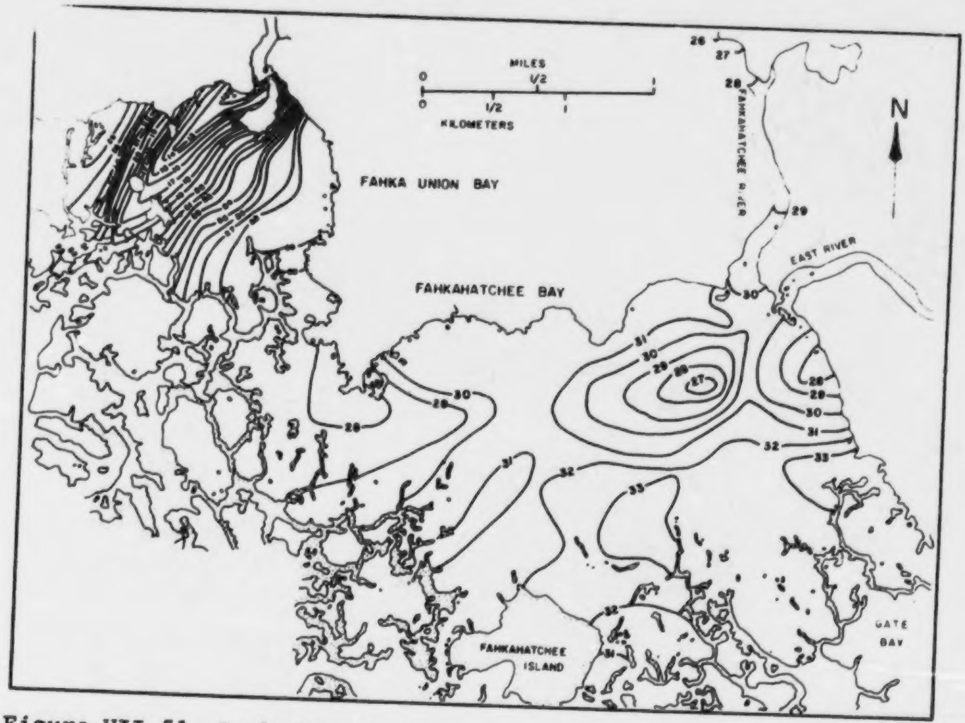

MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
26
27
28
29
30
31
30
29
28
27
28
29
30
31
32
33
28
30
31
32
33
28
32
31

Figure VII-51. Isohaline in Bays at Low Tide (a.m.) on August 10, 1972.

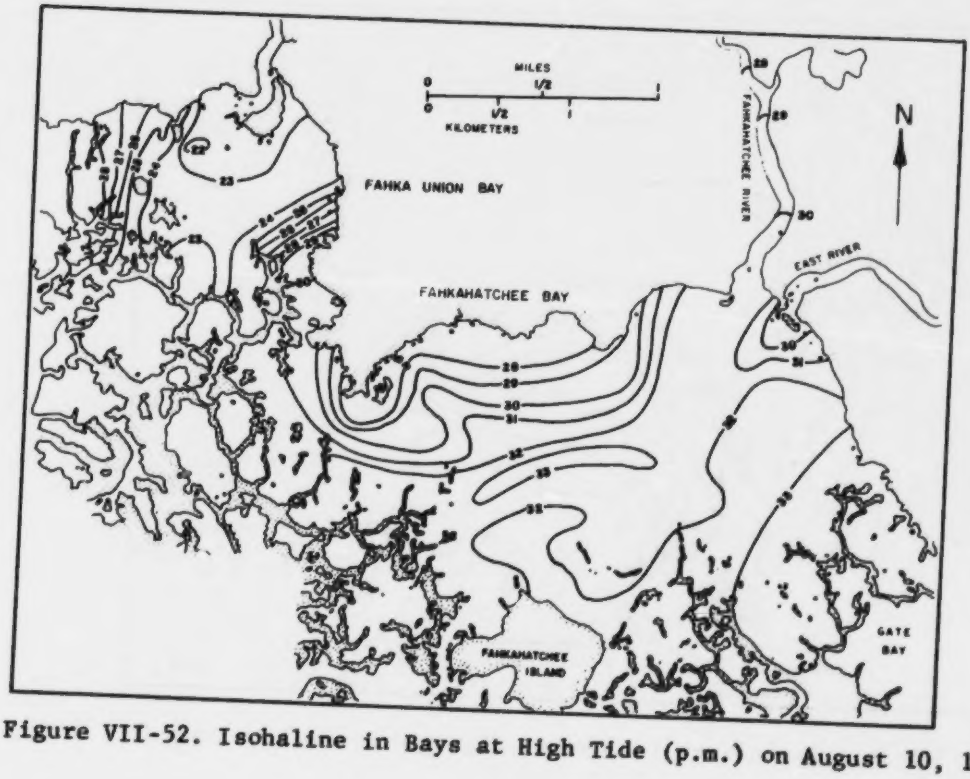
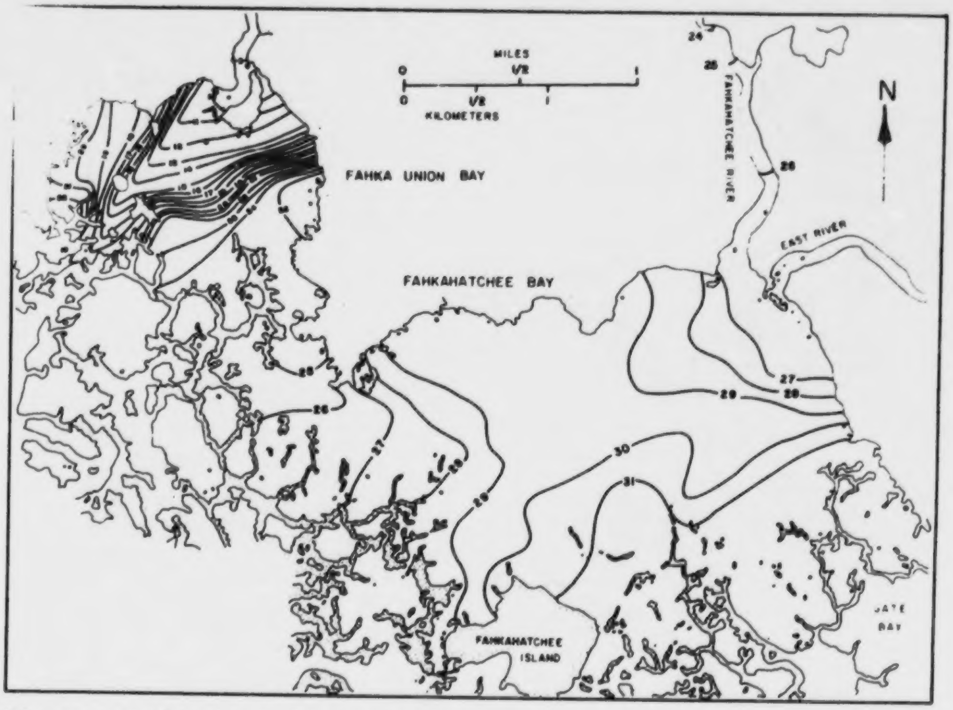

MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
29
29
30
30
31
23
23
28
29
30
31
32
33
32
33

Figure VII-52. Isohaline in Bays at High Tide (p.m.) on August 10, 1972.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FAHKAHATCHEE RIVER
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FAHKA UNION BAY
EAST RIVER
FAHKAHATCHEE BAY
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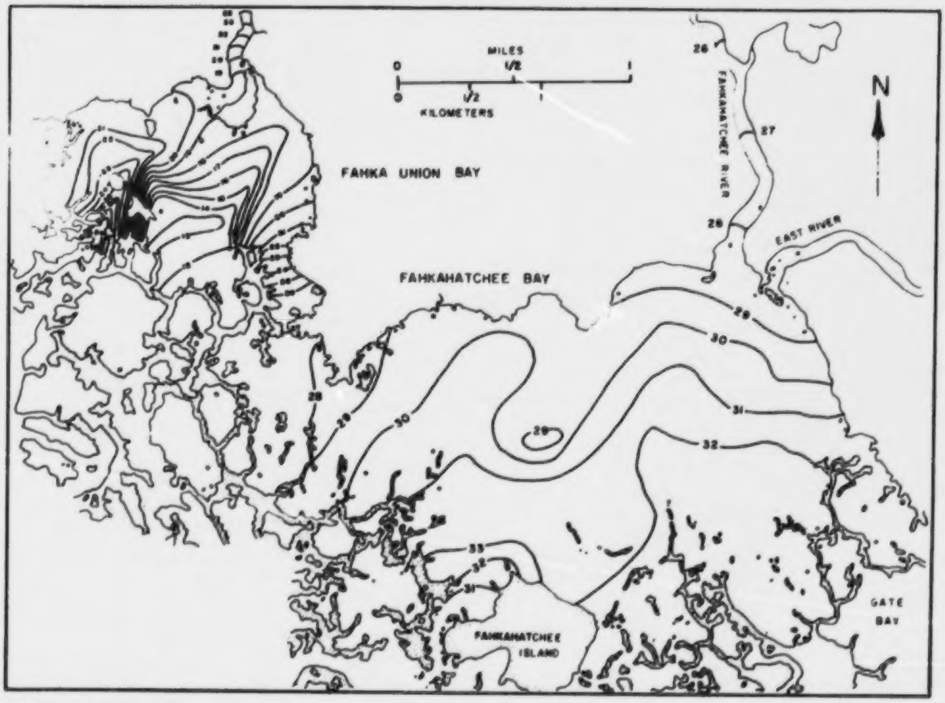
31
GATE BAY
FAHKAHATCHEE ISLAND

Figure VII-53. Isohaline in Bays at Low Tide (p.m.) on October 31, 1972.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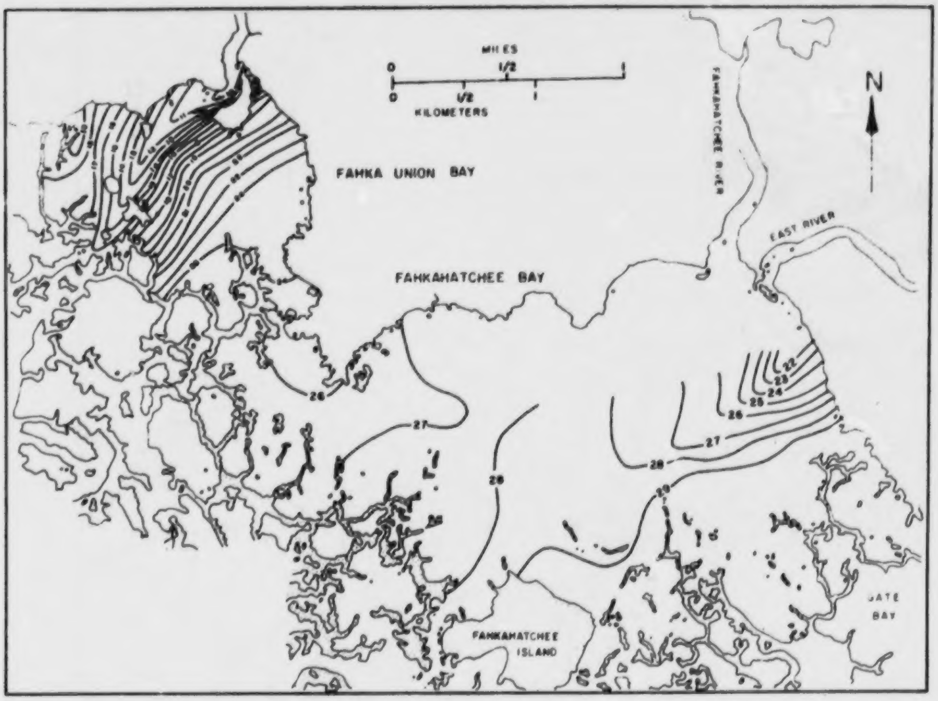
FAHKAHATCHEE ISLAND

Figure VII-54. Isohaline in Bays at High Tide (a.m.) on October 31, 1972.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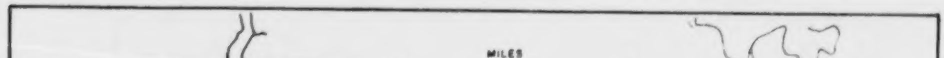
FAHKAHATCHEE ISLAND
GATE BAY

Figure VII-55. Isohalines in Bays at Low Tide (a.m.) on Dec 7, 1972.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FAHKAHATCHEE BAY
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EAST RIVER
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FAHKAHATCHEE ISLAND
GATE BAY

Figure VII-56. Isohalines in Bays at High Tide (p.m.) on Dec 7, 1972.

On April 7, 1972 the average salinity in Fahka Union Bay on the ebb and flood tides (Figures 57 and 58) were 35.3 ppt and 36.5 ppt, respectively, compared to 36.7 ppt and 36.9 ppt in Fahkahatchee Bay (Figures VII-59 and 60). During both the ebb and flood only 37 ppt isohaline was evident in Fahkahatchee Bay. Salinities in the Gulf of Mexico off Round Key approximated 36.5 ppt. It is evident that upland runoff was small and that very little mixing occurred between Fahkahatchee Bay and the Gulf of Mexico during this period. Bay salinities became greater than off-shore salinities due to these small runoffs and minor exchange rates (Figure VII-42) permitting evaporation in the upper bay and hence a build-up of salts and other solids. Salinities at Station 53, some 4.34 kilometers (2.7 mi) above the mouth of the Fahkahatchee River, were in the order of 36.3 ppt to 36.8 ppt compared to 32 ppt near the mouth of the Fahka Union Canal on the flood tide, indicating that even during periods of extreme low flows in Fahka Union Canal, effects of drainage are evident.

Extreme differences in salinity patterns in the bays were noted in the June 27 survey (Figures VII-49 and 50). Isohalines in Fahka Union Bay ranged from 3 ppt to 8 ppt compared with 9 ppt to 21 ppt in Fahkahatchee Bay (Figure VII-44). From the isohalines it appears that during high runoff periods the GAC Canal has an effect on the western most portion of Fahkahatchee Bay. For instance, the 9 ppt to 13 ppt range is not evident in the vicinity of the Fahkahatchee and East Rivers. Ignoring the exchange effect from Fahka Union Bay would give a salinity range of 14 ppt to 21 ppt in Fahkahatchee Bay. During the ebb tide the average salinity in Fahka Union and Fahkahatchee Bays were 6.5 ppt and 17.1 ppt, respectively, a difference of 10.6 ppt. Again, ignoring exchange effects from Fahka Union, would increase the average salinity in Fahkahatchee Bay to 17.9 ppt, therefore, increasing the difference between the two bays to 11.4 ppt. The same general characteristics exist on the flood tide (Figure VII-50).

The greatest observed salinity gradient in Fahka Union Bay occurred on a low ebb tide during the morning of August 10. During this ebb the majority of water entering Fahka Union Bay remained in the channel, or was transported out of the bay via the channel. There was very little evidence of canal water being transported across the bay or through the small cut at the extreme northeast side of the bay. Within this cut the salinity gradient was approximately 1.8 ppt per 30.5 meters (100 ft). During the ebb the salinity range in Fahka Union and Fahkahatchee Bays were 11 ppt to 29 ppt and 27 ppt to 33 ppt, respectively. On the flood tide the salinity range in Fahka Union Bay increased from 22 ppt to 30 ppt and the average salinity increased from 20.5 ppt to 22.0 ppt. Only a minor change took place in Fahkahatchee Bay with the salinity range increasing from 28 ppt to 33 ppt and the average increasing from 26.4 ppt to 27.3 ppt.

The concentric isohalines in Fahkahatchee Bay the mornings of August 10 (Figure VII-51) and October 31 (Figure VII-53) are indicative of a changing tide. In general, the change of tide during the morning run would occur while the sampling team was in the eastern side of Fahkahatchee Bay. Since the afternoon run was conducted in reverse of the morning run the tide change occurred while sampling in Fahka Union Bay.

The average salinity was always lower in Fahka Union Bay than Fahkahatchee Bay (Figures VII-57 through 60). The maximum observed differences occurred during the June 27 survey when flows in the Fahka Union Canal were near a maximum.

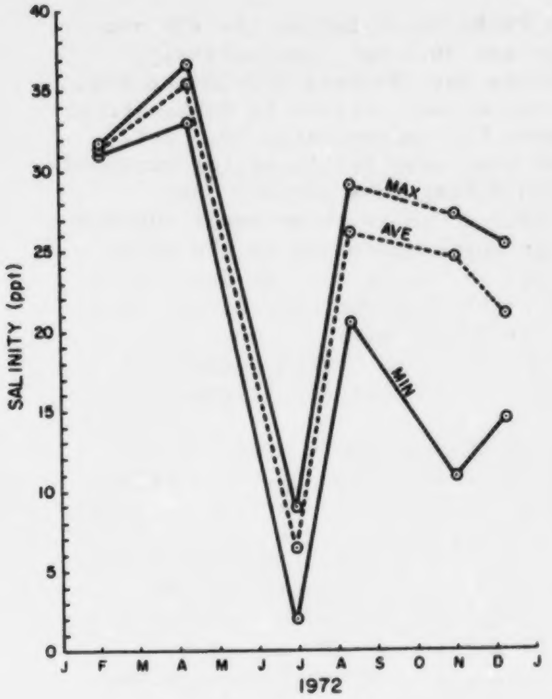


Figure VII-57. Salinity Variations in Fahka Union Bay at Low Tide During 1972.

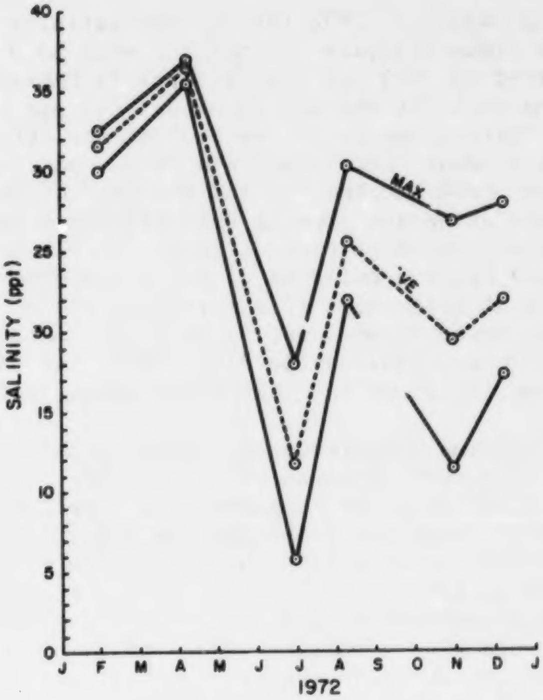


Figure VII-58. Salinity Variations in Fahka Union Bay at High Tide During 1972.

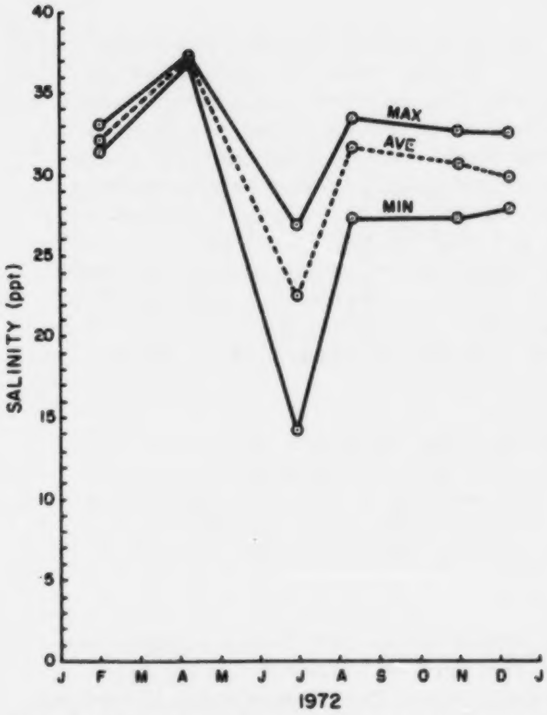


Figure VII-59. Salinity Variations in Fahkahatchee Bay at Low Tide During 1972.

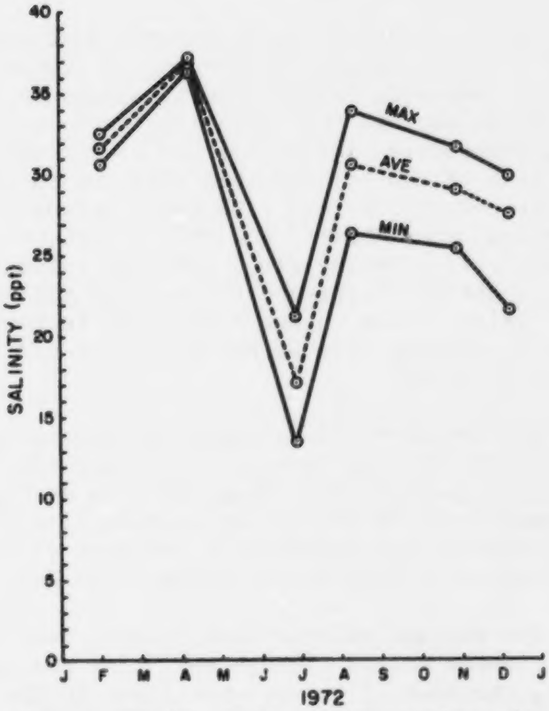


Figure VII-60. Salinity Variations in Fahkahatchee Bay at High Tide During 1972.

Flows peaked in the Fahka Union Canal in September (Figure VII-7). Conceivably, had a salinity run been conducted during the peak runoff period the differences would have been even greater.

Salinities in the Fahka Union Canal-Bay-Pass transect always increased downstream from U.S. 41 on the ebb tide (Figure VII-61). During periods of high flow the maximum gradient occurred downstream from the mouth of the Fahka Union Canal. During periods of low flow the maximum gradient occurred in the canal. During the low runoff study on April 7 the salinity increased from 11.6 ppt at U.S. 41 to 32.2 ppt at the mouth of Fahka Union Canal as compared to 0.9 ppt to 2.1 ppt during the wet month of June. Salinities at the mouth of Fahka Union Pass varied from a low of 30.3 ppt on December 7 to a high of 36.6 ppt on April 7 on ebb tide. On flood tide (Figure VII-62) the salinity range increased to a low of 33 ppt on August 10 to a high of 36.9 on April 7.

For comparative purposes Figure VII-63 is comparable to that portion of Figures VII-61 and 62 below 8.5 kilometers (5.3 mi) labled "PASS." As would be expected, the salinity gradient below Fahka Union Bay was always greater than that below Fahkahatchee Bay. On April 7 ebb tide, the salinity actually decreased seaward of Fahkahatchee Bay. The greatest salinity gradient seaward of Fahkahatchee Bay occurred on the June 27 ebb tide with an increase of 10.4 ppt from 21.6 ppt to 33.0 ppt. This compared with a change of 18.6 ppt from 12.1 ppt to 30.7 ppt in Fahka Union Bay on the same date. With the exception

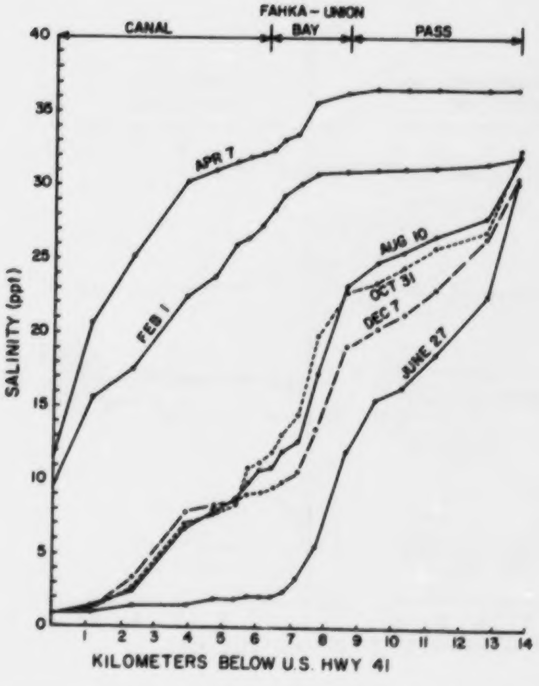


Figure VII-61. Salinity Variations in the Fahka Union Canal at Low Tide During 1972.

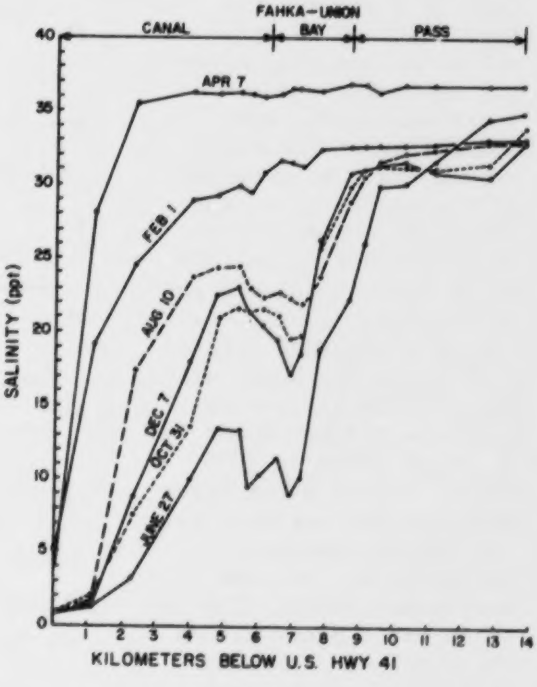


Figure VII-62. Salinity Variations in the Fahka Union Canal at High Tide During 1972.

of June 27 the salinity differences seaward of Fahkahatchee Bay were less than 1.5 ppt compared to 12.7 ppt in the Fahka Union Pass.

In conjunction with the detrital transport study of October 17, 18 and 19 (Section IX), six time series vertical salinity measurements were conducted over a tidal cycle in Fahka Union Bay and Fahkahatchee Bay. The Fahka Union Canal and Fahka Union Pass stations (Figure VII-64) are at the same general locations as are salinity stations 1 and 9 (Figure VII-43), respectively. The Fahkahatchee River and East River stations (Figure VII-65) are located approximately half way between salinity stations 50 and 51 and approximately 183 meters (600 ft) above the mouth of the East River, respectively. Fahkahatchee Pass and West Pass stations (Figure VII-66) are located between salinity stations 31 and 32 and at station 40, respectively.

As observed from Figure VII-64, surface salinities in the canal varied from a high of 18 ppt on the flood tide to a low of 2.5 ppt on the ebb tide. Within the pass, some 1.1 miles downstream, the surface salinities varied from a low of 13 ppt to a high of 28 ppt. Both stations exhibited stratification during portions of the tidal cycle. Within the canal the greatest stratification occurred some two hours after the low slack with salinity at the surface of 3 ppt and the five foot depth of 15 ppt. Canal water was well mixed for approximately six hours during the ebb. Maximum stratification within the Pass occurred at the beginning of the ebb. Salinities at the one, five and seven foot depth were 18 ppt, 26 ppt and 27 ppt, respectively. The Pass remained stratified until two hours after the ebb slack. Restratification did not occur on the high slack at 2300 hours. Fresh water input from the GAC drainage system was approximately 14,151 l/sec (500 cfs) during the study. Had the study taken place around the first of September with fresh water input in the order of 6,295 l/sec (2,200 cfs) the

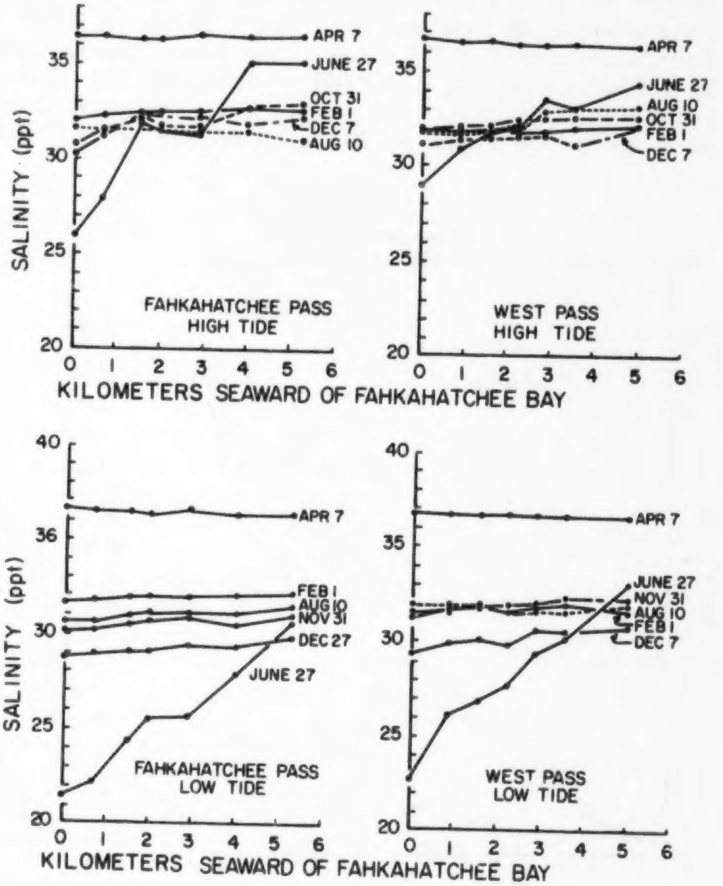


Figure VII-63. Salinity Variations in Fahkahatchee Pass and West Pass During 1972.

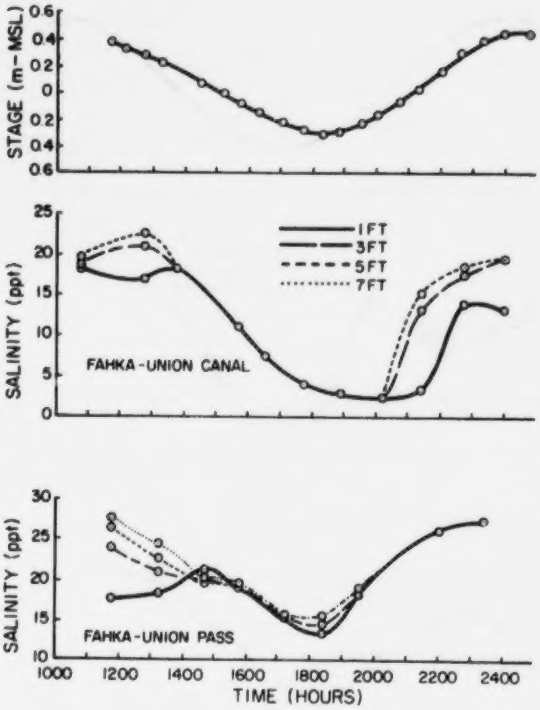


Figure VII-64. Time, Stage and Salinity Variations in Fahka Union Canal and Fahka Union Pass on Oct 17, 1972.

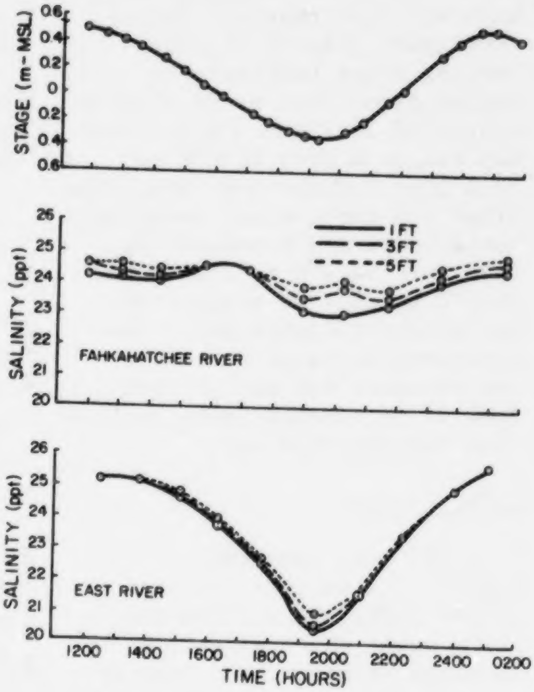


Figure VII-65. Time, Stage and Salinity Variations in Fahkahatchee River on Oct 18, 1972.

degree of stratification at both stations would have been presumably greater.

Salinity stratification existed at all four stations in Fahkahatchee Bay (Figures VII-65 and 66) but to a much lesser degree than in Fahka Union Bay. Differences at the 0.30 and 1.52 meter (1 and 5 ft) depth were generally less than 1.0 ppt. Over the tidal cycle, salinities in Fahkahatchee River ranged from a high of 25.8 ppt to a low of 23 ppt as compared with 25.7 ppt to 20.6 ppt in the East River. Based upon salinity differentials it is apparent that the greatest input of fresh water into the northern end of Fahkahatchee Bay is from the East River. This was confirmed by the previously discussed circulation study.

As observed from the salinity profiles in Figure VII-66, a greater percentage of fresh water exits via Fahkahatchee Pass than West Pass. The minimum salinities in Fahkahatchee Pass and West Pass during the October 19 survey were 26 ppt and 27 ppt, respectively. Likewise, maximum salinities were 30 ppt and 30.7 ppt, respectively at the flood slack.

In conjunction with the bi-monthly salinity studies, measurement of estuary water temperatures were also made. Regardless of the tidal phase, the yearly temperature profiles (Figure VII-67) are presented on a morning and afternoon basis. The average water temperature differences between

Fahka Union and Fahkahatchee Bays are less than one degree centigrade (Figure VII-67). Morning water temperatures ranged from a low of 24.1° C to a high of 32.7°C in Fahka Union Bay compared with 23.6°C to 32.1°C in Fahkahatchee Bay. The afternoon temperature range in Fahka Union and Fahkahatchee Bays were 24.7°C to 33.1°C and 24.3°C to 32.7°C, respectively. The slightly higher water temperatures in Fahka Union Bay are probably due to the fact that it is somewhat more shallow than Fahkahatchee Bay.

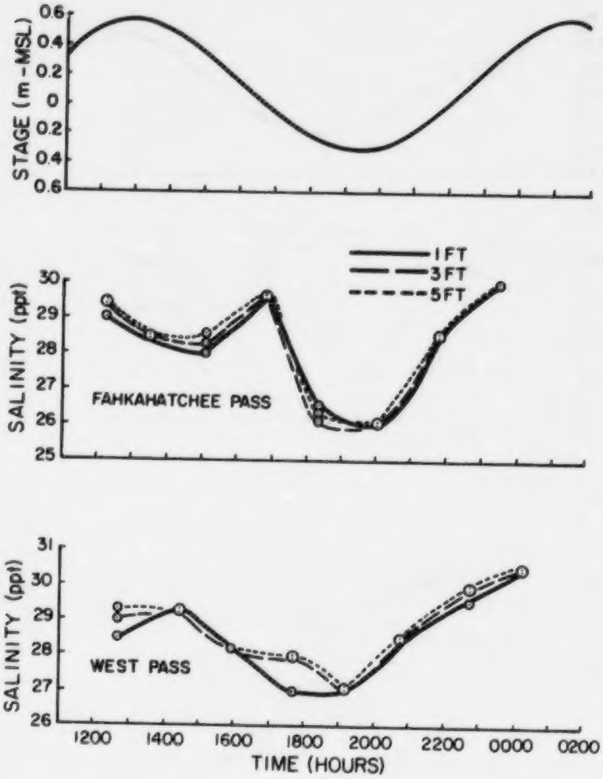


Figure VII-66. Time, Stage and Salinity Variations in Fahkahatchee Pass and West Pass on Oct 19, 1972.

Tidal Fluctuations

The most important ecological factor in an estuary is the tide, since it is the prime agent which effects the exchange of water, and its vertical range generally determines the extent of tidal flats which may be exposed or submerged with each tidal cycle. The action of the tides against the volume of river water discharged into an estuary results in a complex system whose properties vary according to the structure of the estuary as well as the magnitude of the river flow and range of tide (Emery and Stevenson, 1971).

A Stevens Type A, Model 71, Stage Recorder was installed at the southern side of Fahkahatchee Bay in the vicinity of Fahkahatchee Pass (Figure VII-1) in order to assess the tidal fluctuations in the bay and to provide information from which to conduct other studies. Due to lack of stage recorders, this portion of the study was conducted only from June to December 1972.

There is a greater tidal differential in Fahkahatchee Bay during the spring tide periods than the neap tide period (Figure VII-68).

Due to the shallowness of both Fahkahatchee and Fahka Union Bays, wind produces a very pronounced effect on the water elevations of the bays. During northern (continental) winds the salt marshes above the bays, and the bays themselves are depleted of a significant portion of their water.

During the study period the lowest observed tides occurred on December 16, 1972, when the surface water elevation fell to 81.4 centimeters (2.67 ft) below MSL. At this time only 78 percent of Fahkahatchee [illegible]y and 47 percent of Fahka Union Bay were inundated.

The highest elevation occurred on June 19, 1972, during the influence of Hurricane Agnes. During this period of high southwesterly winds the water elevation peaked at 88.4 centimeters (2.90 ft) above MSL. The highest low tide occurred on this date at 39.6 centimeters (1.30 ft) above MSL. The greater difference in tidal magnitude also occurred on June 19 with the low high tide at 83.2 centimeters (2.73 ft) above MSL, and the low low tide at 49.7 centimeters (1.63 ft) below MSL. This 1.33 meter (4.36 ft) decrease in tidal amplitude accounted for over 9,800,000 cubic meters (7,950 ac-ft) of water being removed from Fahkahatchee Bay and contiguous uplands.

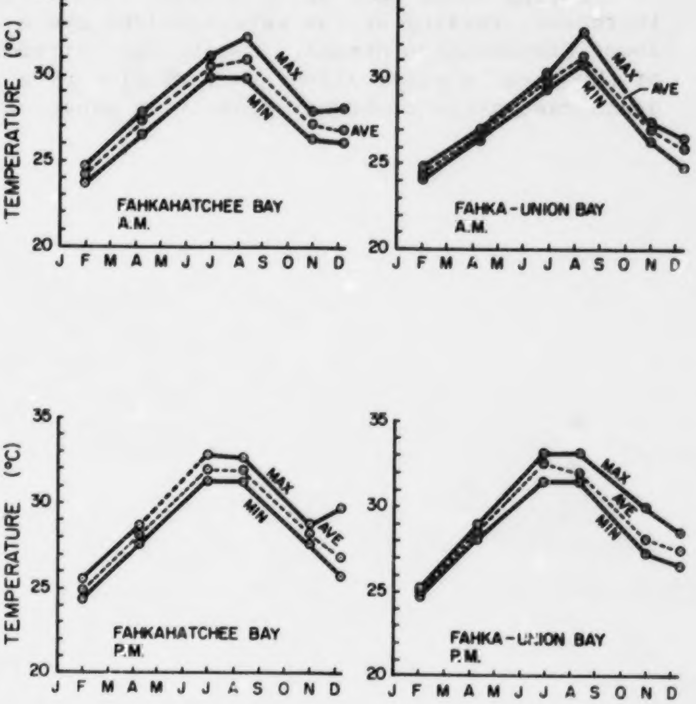


Figure VII-67. Annual Temperature Ranges in Fahka Union and Fahkahatchee Bays During 1972.

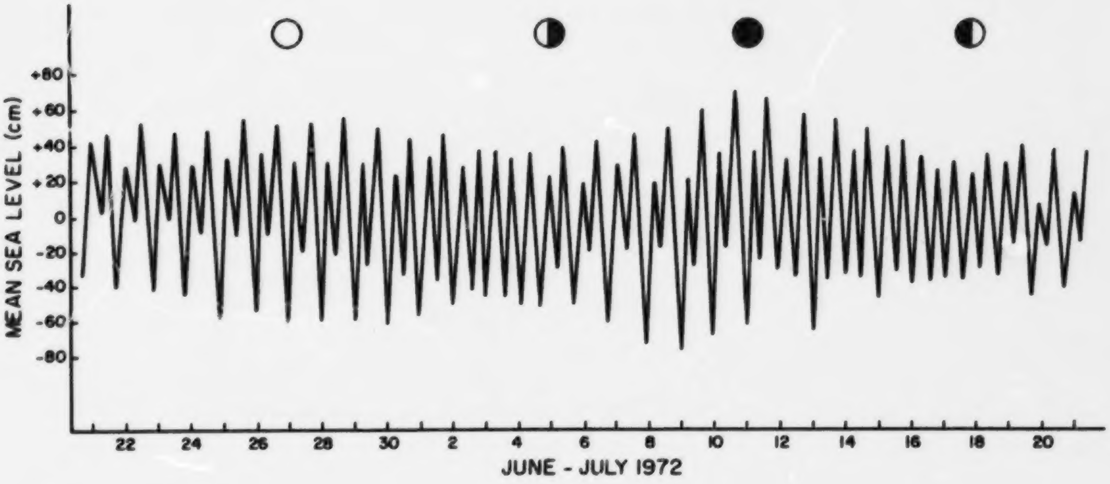


Figure VII-68. Tidal Amplitudes With Lunar Phase for Fahkahatchee Bay.

During these periods of oceanic winds, tidal amplitudes are greatly increased, raising saline waters inland above U.S. 41 in the vicinity of lower Fahkahatchee Strand. Due to the extremely small topographic relief of the area, a water elevation variation of a few inches can inundate or drain vast areas of highly productive mangrove and salt marsh areas.

VIII - BAY BOTTOM CHARACTERISTICS AND SEDIMENT DEPOSITION

INTRODUCTION

Southwestern Florida coastal areas are of increasing concern to those who are interested in the changes to the natural and esthetic qualities of the estuarine environments. One of the major factors affecting the estuarine system is sedimentation; however, little information is available.

The purpose of this section is to identify the bottom characteristics of Fahkahatchee and Fahka Union Bays. Further, the Bays were investigated for sedimentation rates followed by coring based upon sedimentation rates.

Sediment and core samples were analyzed for organic and inorganic functions on dry weight basis.

METHODS

Bottom Characteristics

Fahkahatchee and Fahka Union Bays were staked on a 300 by 300 meter grid system (Figure VIII-1) which resulted in 103 and 24 sampling sites in Fahkahatchee and Fahka Union Bays, respectively.

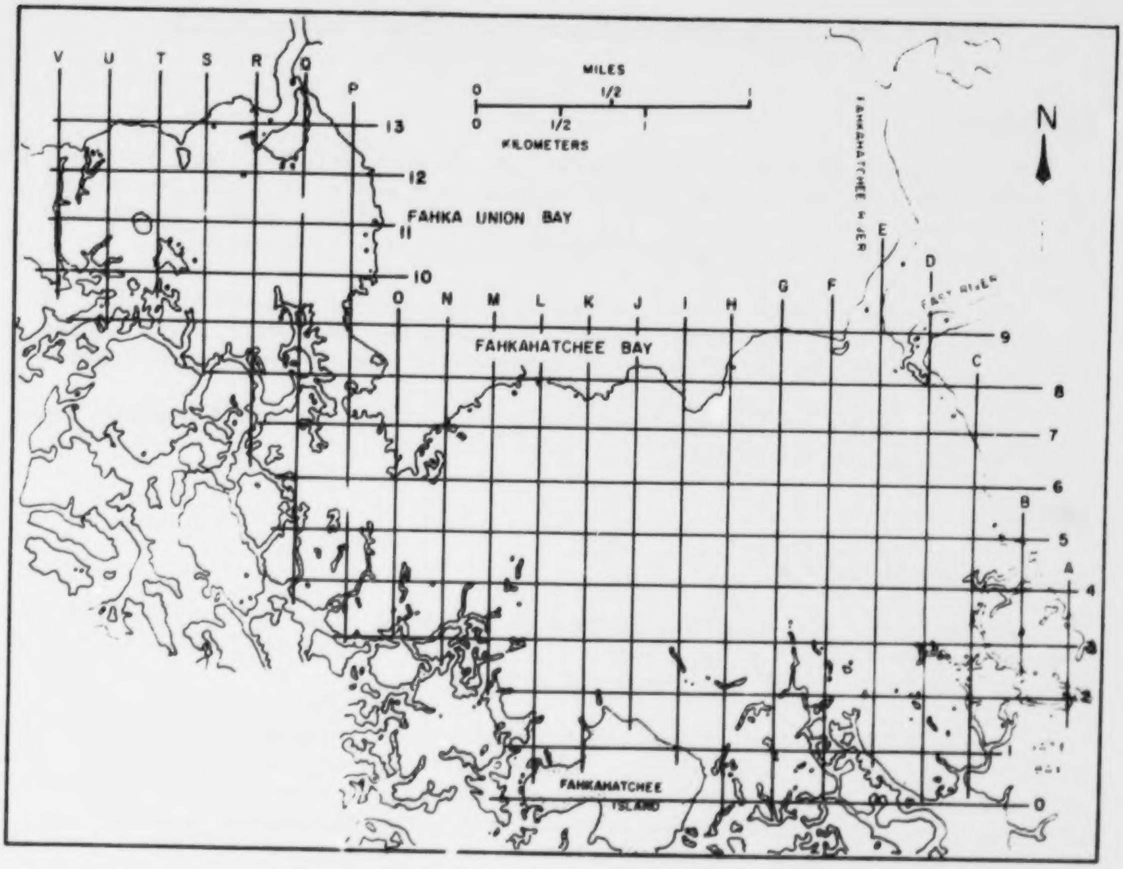
Bottom deposits were collected from each grid intersection by means of a 15 by 15 centimeter Ekman dredge. Bottom sediments were classified by visual examination into three somewhat arbitrary classifications of mud, sand or shell. Combinations of the three types were delineated by noting the predominant, secondary and tertiary characteristic.

Sedimentation Rates

To assess the amount of organic and inorganic sediment depositing in the two bays, sediment traps were installed on the bay bottoms. The traps (Braidech, Gehring and Klevens, 1972) were constructed from PVC pipe and contained removable inner cylinders to reduce turbulence and to increase settling efficiency within the traps (Figure VIII-2).

The traps were placed on the bay bottoms at somewhat arbitrary grid locations. Twenty-eight sites presented on Figure VIII-3 were used with 14 sites per bay. Fahka Union Bay was reasonably proportioned by the traps; however, the 14 traps used in Fahkahatchee Bay were only sufficient to cover the area below the mouths of Fahkahatchee and East Rivers.

The traps were installed on July 17, 1972, and were serviced every two weeks until removal on November 20, 1972. When servicing, a protective cap was placed over the open end of the traps to prevent any resuspended material from entering the traps during retrieval and installation. Contents of the traps were then transferred to a large container (approximately 10 liters), resuspended by hand mixing, and sub-sampled by use of a 300 milliliter BOD bottle. Subsequently, the traps were cleaned and replaced on the bay bottoms.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FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
FAHKAHATCHEE ISLAND

Figure VIII-1. Grid System.

Sub-samples were analyzed for salinity, dry weight and ash free dry weight. Appendix C describes the laboratory methodology and computations to arrive at the organic and inorganic sedimentation rates. The computed bi-weekly rates are in terms of grams per meter squared per day for each of the 28 stations.

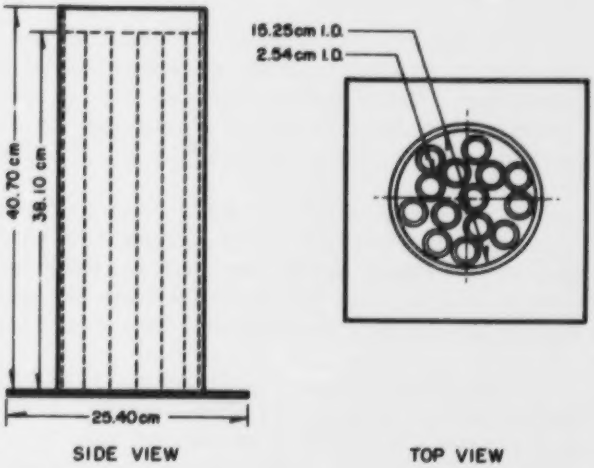
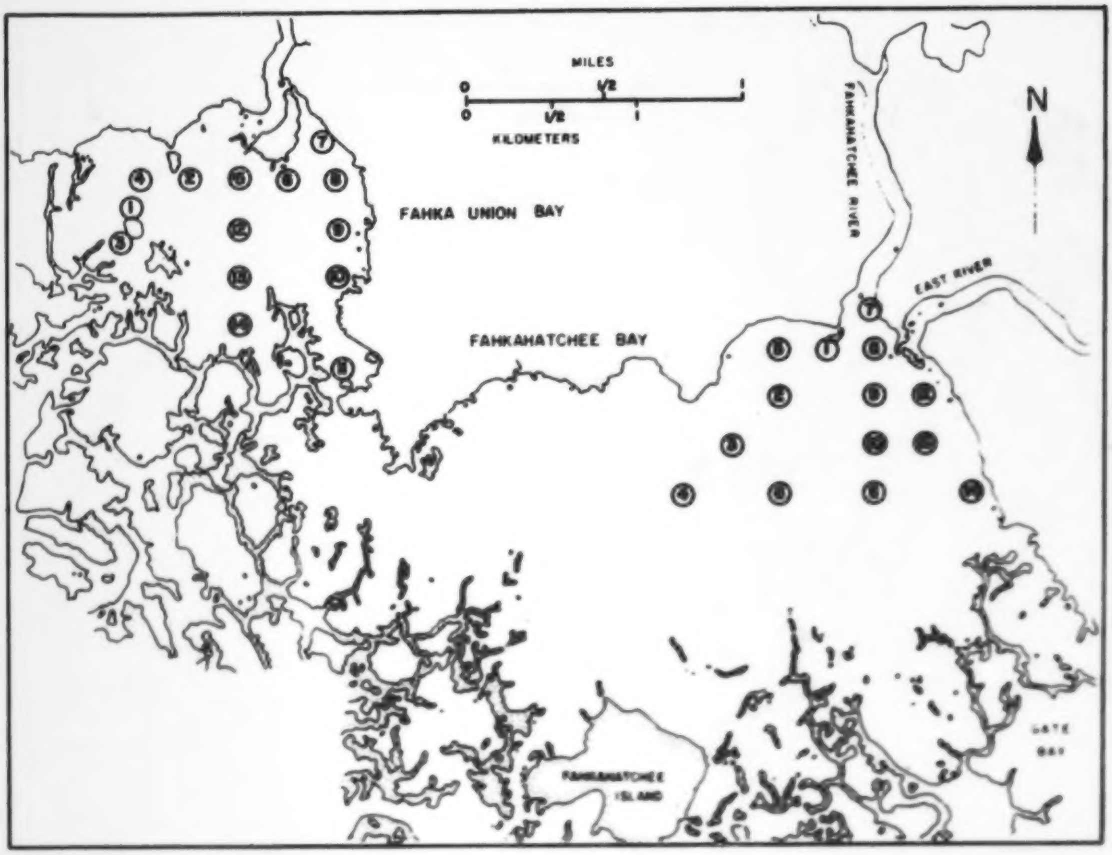

15.25cm I.D.
2.54cm I.D.
40.70 cm
38.10 cm
25.40cm
SIDE VIEW
TOP VIEW

Figure VII-2. Sedimentation Trap.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FAHKA UNION BAY
FAHKAHATCHEE RIVER
EAST RIVER
FAHKAHATCHEE BAY
FAHKAHATCHEE ISLAND
GATE BAY

Figure VIII-3. Sediment Trap Locations.

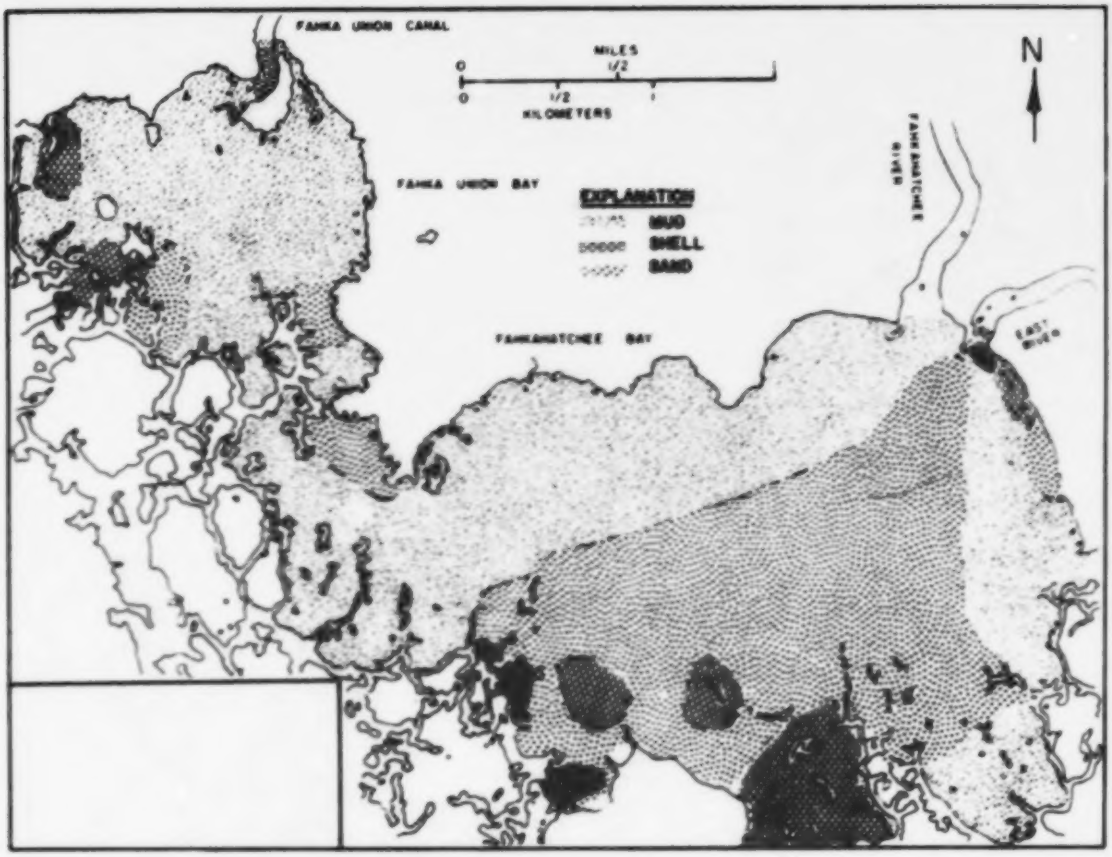
Coring

Inorganic and organic content of the top 40 centimeters of the bay bottoms was assessed by coring. The coring devices used were 3.5 centimeter I. D. PVC pipe cut to one meter lengths. These open ended pipes were eased into the soft bay bottoms to approximately 2/3 of their length. Rubber stoppers were then placed on the top and bottom of the cores. The bottom stopper was installed by digging alongside of the in-place core to the tube end. Samples were then returned to the laboratory for analysis.

RESULTS

Bottom Characteristics

The distribution of bottom types is illustrated in Figure VIII-4. The boundaries drawn between the three types were not clearly defined by the field survey and hence serve only to show the general trend in the distribution of the sediments. Table VIII-1 presents the observed substrate characteristics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FAHKA UNION BAY
EXPLANATION
MUD
SHELL
SAND
FAHKAHATCHEE BAY
EAST RIVER

Figure VIII-4. Distribution of Bottom Characteristics.

of Fahka Union and Fahkahatchee Bays in order of predominant substrate. For example, the substrate designated MSO at Grid P-9 indicates that the sediment sample was predominantly mud with sand to a lesser extent and also some shell fragments present. A summary of the substrate observations is presented in Table VIII-2.

Inland bays of the Ten Thousand Islands are generally characterized as "muddy" bays. Fahkahatchee and Fahka Union Bays are no exception. Approximately 52 percent of Fahkahatchee Bay and 76 percent of Fahka Union Bay is mud. Mud is present in all of Fahka Union Bay and in 79 percent of Fahkahatchee Bay.

Oyster bars are found in both bays, especially on bottoms contiguous to the shallow mangrove islands. Where oysters were found only as extensions of the mangroves they were not considered to be characteristic of the bottom. The largest areas of oysters were found in the mouths of Fahkahatchee and East Rivers and the southeastern side of Fahkahatchee Bay. Smaller concentrations of oysters were found on the northeast and west side of Fahka Union Bay near the mouth of the Fahka Union Canal.

Table VIII-1. Substrate Characteristics in Fahka Union and Fahkahatchee Bays.

Grid	Substrate[a]	Grid	Substrate[a]	Grid	Substrate[a]
Fahka Union Bay					
P-9	MSO	Q-13	MO	S-11	SMO
P-10	SO	Q-15	O	S-12	M
P-11	MSO	R-10	MSO	S-13	MS
P-12	MO	R-11	M	T-11	OS
P-13	MO	R-12	M	T-12	M
Q-9	MOS	R-13	MS	T-13	M
Q-11	M	R-14	MSO	U-12	MS
Q-12	M	S-10	SM	U-13	O
Fahkahatchee Bay					
C-1	M	G-3	SO	K-4	SO
C-3	M	G-4	SO	K-5	SO
C-4	MO	G-5	SM	K-6	MO
C-5	MS	G-6	SMO	K-7	M
C-6	MS	G-7	MS	K-8	MO
C-7	SM	G-8	MS	L-1	O
D-1	M	G-0	M	L-2	SO
D-2	MO	H-1	OS	L-3	SM
D-3	SOM	H-2	SMO	L-4	MO
D-4	M	H-3	SMO	L-5	SO
D-5	MS	H-4	SM	L-6	MS
D-6	M	H-5	SO	L-7	MS
D-7	M	H-6	SM	L-8	MSO
D-8	MSO	H-7	MO	M-3	OS
E-1	MSO	H-8	MS	M-4	SM
E-2	SM	H-9	M	M-5	MS
E-3	SMO	I-1	SMO	M-6	MSO
E-4	SM	I-2	SMO	M-7	MS
E-5	SM	I-3	OS	M-8	M
E-6	SM	I-4	SM	N-4	MO
E-7	SOM	I-5	SM	N-5	MS
E-8	SO	I-6	MS	N-6	MS
E-9	M	I-7	M	N-7	M
F-2	SMO	I-8	MS	O-4	MO
F-3	SMO	J-2	SO	O-5	MS
F-4	SMO	J-3	SO	O-6	MS
F-5	SMO	J-4	S	O-7	SO
F-6	SMO	J-5	SM	P-5	MS
F-7	SMO	J-6	M	P-6	MS
F-8	MSO	J-7	M	P-7	MSO
F-9	MO	J-8	MO	P-8	SO
G-0	O	K-1	MOS	Q-5	M
G-1	OS	K-2	SO	Q-7	MO
G-2	OS	K-3	OS	Q-8	M

[a] M - mud, S - sand, O - shell.

Table VIII-2. Summary of Substrate Characteristics in Fahka Union and Fahkahatchee Bays.

	Primary characteristic		Secondary characteristic		Tertiary characteristic	
	Area-ha.	% of bay	Area-ha.	% of bay	Area-ha.	% of bay
Fahka Union Bay						
Mud	143.1	75.6	20.4	10.8	25.8	13.6
Sand	20.4	10.8	67.7	35.8	16.8	16.8
Shell	25.8	13.6	5.8	3.1	17.6	17.6
Totals	189.3	100.0	93.9	49.7	60.2	48.0
Fahkahatchee Bay						
Mud	386.8	52.1	183.3	24.7	14.4	1.9
Sand	299.6	40.3	215.2	28.9	11.7	1.5
Shell	56.8	7.6	200.7	27.0	124.8	16.8
Totals	743.2	100.0	599.2	80.6	150.9	20.2

Sandy substrates represent 40.3 percent of the primary substrate of Fahkahatchee Bay and only 10.3 percent of Fahka Union Bay. The largest single area of sandy bottom is in the eastern side of Fahkahatchee Bay from the mouths of Fahkahatchee and East Rivers to Fahkahatchee Pass and West Pass.

Sedimentation Rates

Mean organic and total sedimentation rates for both bays are shown as contours on Figures VIII-5 and 6, respectively. The rates for each station over the sampling period of July 17 to November 20, 1972 (9 biweekly periods) were averaged and plotted so that "sedimentation rate contours" could be developed as shown. Both inorganic and organic rates decrease seaward from the mouths of the tidal rivers and canals. Large velocity changes occur at these apertures to the bays. High rates also occurred near the pass between Fahka Union and Fahkahatchee Bays and also near the pass between Fahkahatchee Bay and Gate Bay to the east. The high concentrations at the first pass can be attributed to velocity decreases in the embayment at this pass. Depositions near the pass between Gate and Fahkahatchee Bays are caused by a stilling basin created during ebbing tides, by the junction of the flows from Fahkahatchee River, East River, Gate Bay and other flows from the east.

Fahka Union Bay consistently had greater sedimentation rates than Fahkahatchee Bay with mean rates of 160.0 gm/m^2/day versus 126.5 gm/m^2/day (Figures VIII-7 and 8). Throughout the sampling period both bays had gradual rate increases with one two-week period (August 15 - August 29, 1972) having rates nearly twice that of the previous period. Rainfall was relatively high preceding and during this period of high sedimentation rates. Apparently a large quantity of sediment was flushed into the bays at this time.

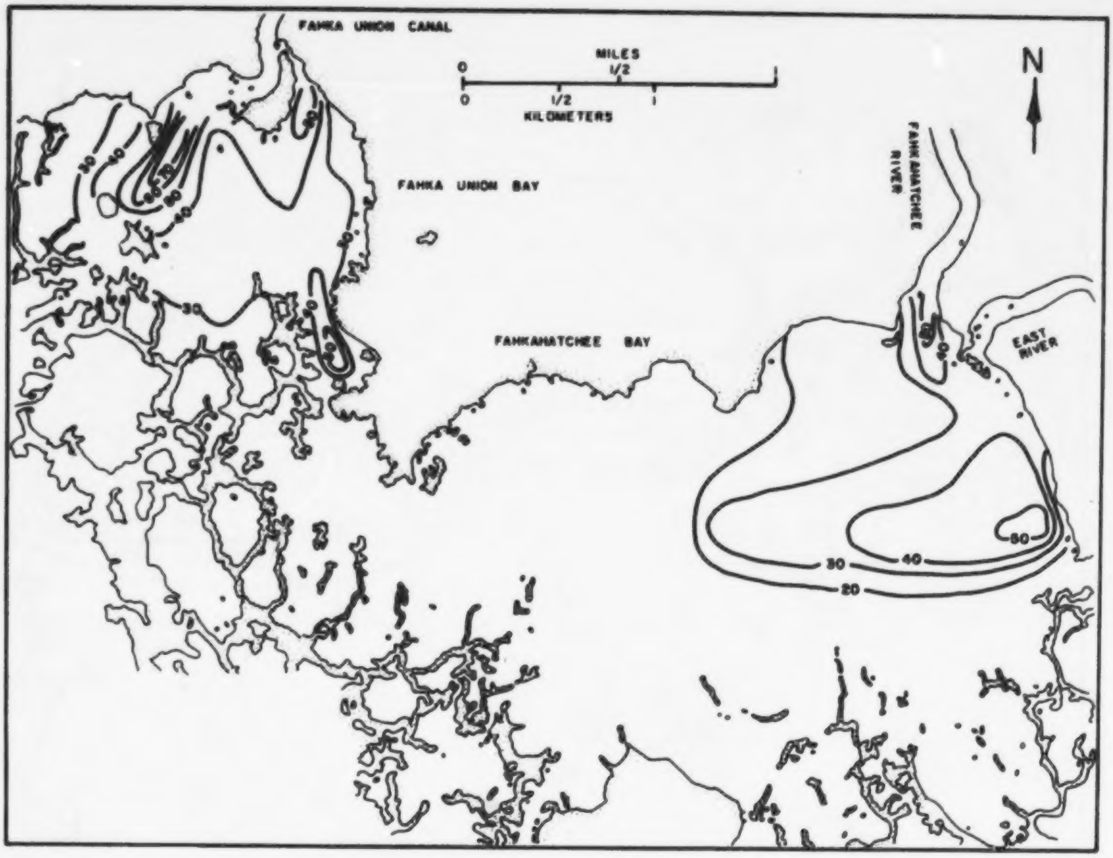

Figure VIII-5. Mean Organic Sedimentation Rate Isopleths in gm/m^2/day, July 17 Through November 20, 1972.

Biweekly mean organic organic fraction, as a percentage of the mean sediment rate, differed little between the two bays (Figure VIII-9). In fact, both bays had approximately 19 percent organic content in their sediment traps in late July and the organic content increased to approximately 33 percent in early October, then decreased to 27 percent in mid-November. Floating periphyton in a decomposing state was observed in both bays during the fall. Possibly a good portion of the increased organic percentage can be attributed to decomposed periphyton.

In order to quantify the sedimentation rates into deposition rates (cm/yr) the specific gravity of the sediment was required. This determination was made by use of a pycnometer bottle (Taylor, 1948). The contents, both organic and inorganic fractions, of all 28 traps for the sampling period of October 10 to October 27, 1972, were composited in order to get a sufficient quantity of material for the test. Subsequent analyses yielded a specific gravity of 2.23 for the material. Applying the density to the mean sedimentation rates for the sampling period (July 17 - November 20, 1972) of 126.5 gm/m^2/day for Fahkahatchee Bay and 160.1 gm/m^2/day for Fahka Union Bay discloses deposition

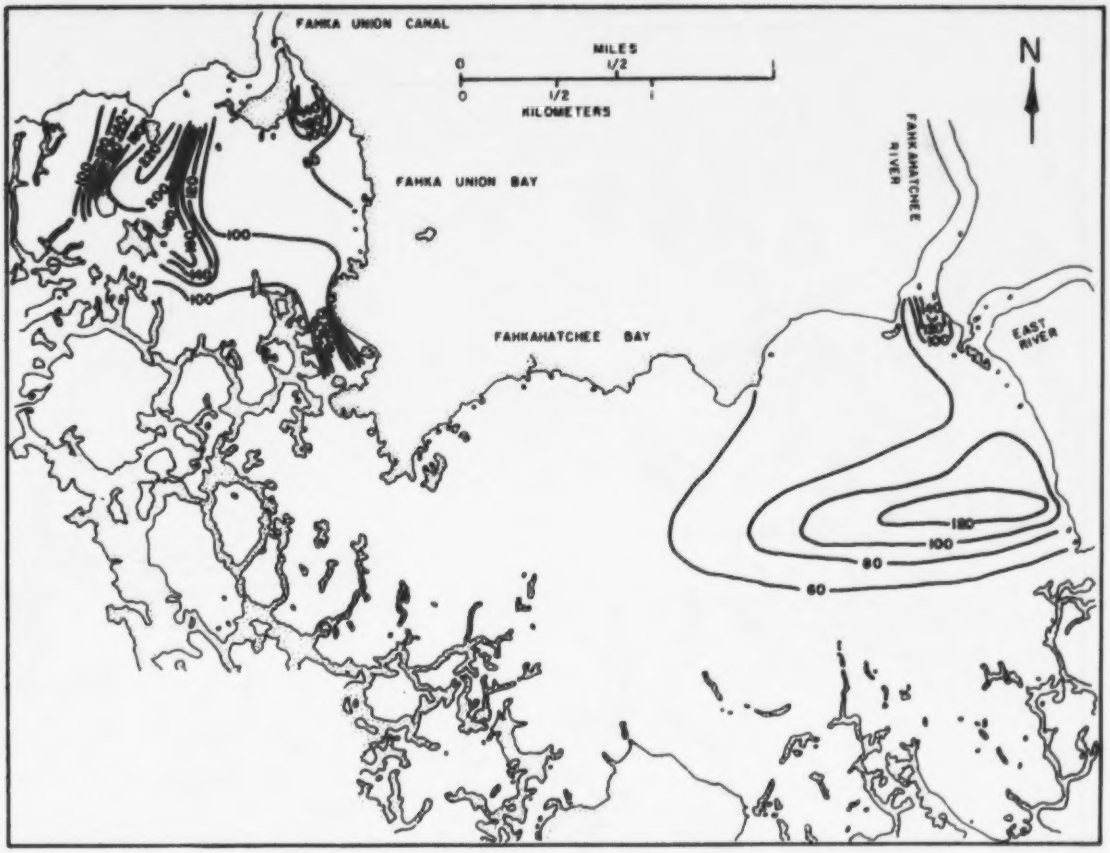
FAHKA UNION CANAL
MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE RIVER
FAHKAHATCHEE BAY
EAST RIVER
100
120
160
200
100
100
120
100
80
60

Figure VIII-6. Mean Total Sedimentation Rate Isopleths in gm/m^2/day, June 17 Through November 20, 1972.

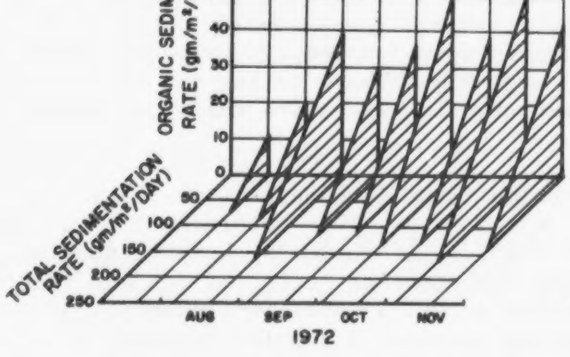

Figure VIII-7. Biweekly Total and Organic Sedimentation Rates for Fahkahatchee Bay.

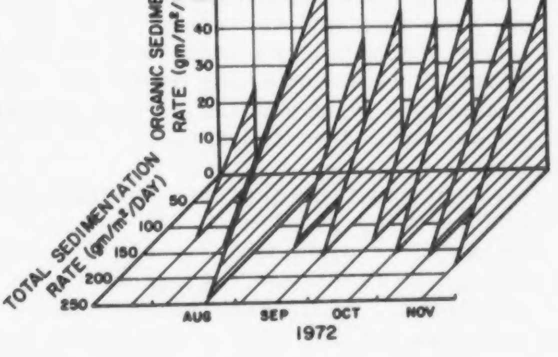

Figure VIII-8. Biweekly Total and Organic Sedimentation Rates for Fahka Union Bay.

rates of 2.31 cm/yr and 2.94 cm/yr, respectively. Resuspension of bottom sediments is obviously occurring in these shallow bays. Several factors such as boat traffic near the traps, bottom foraging marine fishes, shrimp and crabs using the traps as living and feeding habitats, and wind induced wave action are contributors to turbulence and resuspension.

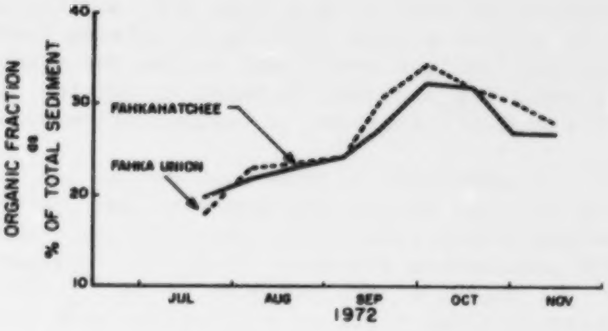

Figure VIII-9. Biweekly Mean Organic Fraction of the Total Trapped Sediment for Fahkahatchee and Fahka Union Bays.

Commercial fishermen, when deploying their gear, probably created some sediment turbulence near the traps; however, tourist and sport-fishing boat traffic was at a low during the sampling period. Fishes and other marine animals found the traps to be suitable homes. Better than 40 percent of the traps serviced (102/252) yielded at least one inhabitant. Appendix D lists the various species found in the traps and also the frequency of occurrence. Certainly the above two contributors are small. However, the third, wind induced wave action, is a strong parameter in creating resuspension in these shallow bays.

A gradual sedimentation rate increase occurred in both bays in conjunction with a seasonal decrease in mean daytime tidal stages. These stages made the bays seasonably shallower and more susceptible to resuspension by strong daytime winds. Figures VIII-10 and 11 present the variation in day and nighttime (0600 - 1800 and 1800 - 0600) windspeeds and tidal stages during the sampling period. The former figure clearly shows that the average daylight windspeed (7.0 mph) exceeded the nightly averages (5.4 mph) over the span of the study period. Unlike the wind, a seasonal decrease in daytime mean tidal stage occurred while the mean nighttime tidal stage increased (Figure VIII-11). The

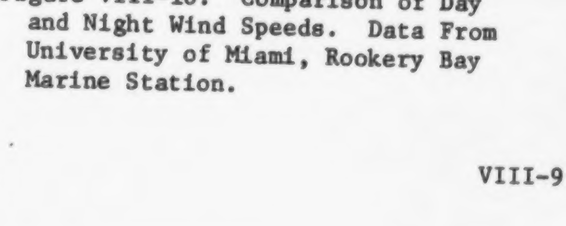

Figure VIII-10. Comparison of Day and Night Wind Speeds. Data From University of Miami, Rookery Bay Marine Station.

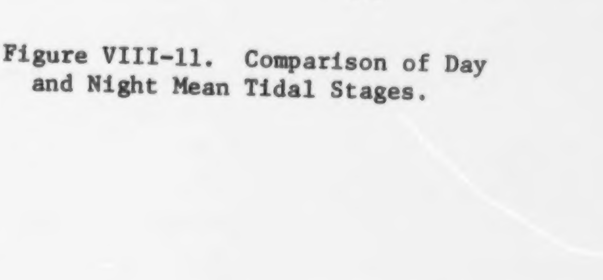

Figure VIII-11. Comparison of Day and Night Mean Tidal Stages.

culmination then is that over the sampling period (July 17 - November 20, 1972) a 30 percent greater turbulence driving force (wind) occurred in the bays during the daylight hours than during the night hours. This, coupled with the accompanying seasonal decrease in daytime tidal stages, appears to have led to a seasonal increase in sedimentation rates.

A comparison of mean trap depths and observed sedimentation rates between the two bays reveal that water column depths are a dominant factor affecting sedimentation rates. The average water column depths at the traps were 87 and 106 centimeters for Fahka Union and Fahkahatchee Bays, respectively. The ratio of the depths of the two bays, 87/106 (.83), is relatively the same as the inverse of the ratio of the average sedimentation rates of the two bays, 126.5/160 (.79). Therefore, one might conclude that during this sampling period the sedimentation rates of the two bays were relatively equal when normalized for depth.

In order to statistically test the validity of the above hypothesis, a linear regression analysis of water column depth to sedimentation rates for each bay was performed. A comparison of the two linear regressions revealed that the slopes and elevations of the linear equations were not significantly different at the five percent level. Figure VIII-12 was constructed from data of both bays with the linear plot described by the equation $y = -192.6 X + 321.8$ ($P < 0.001$).

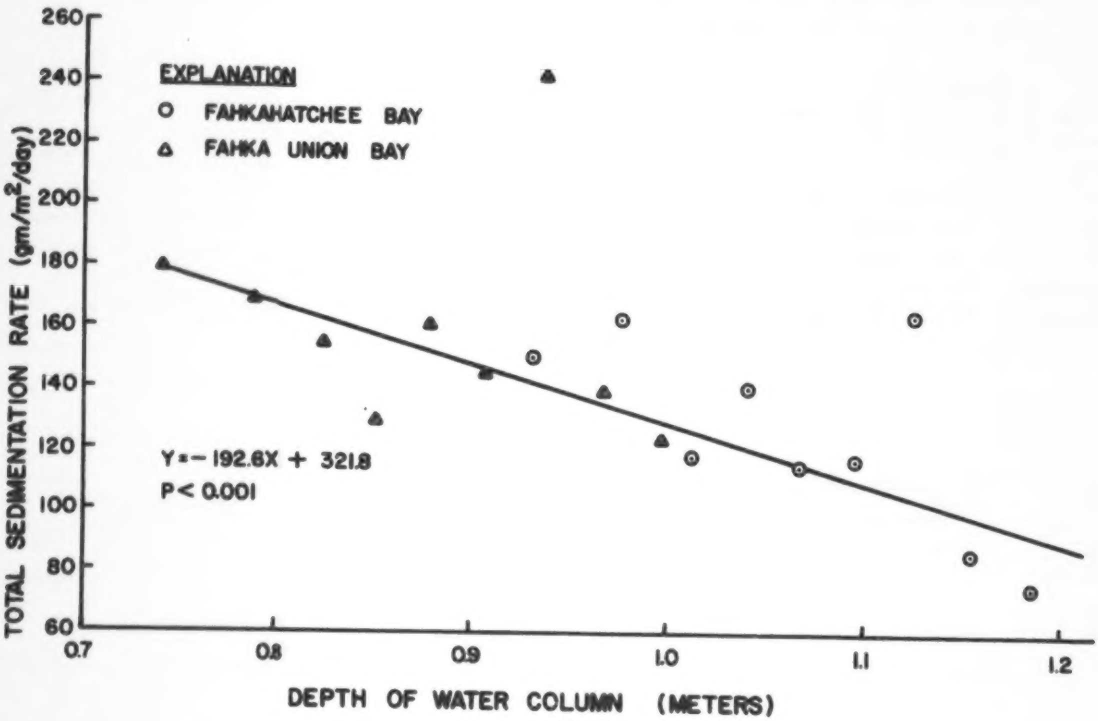

Figure VIII-12. Comparison of Bay Sedimentation Rates to Water Column Depth in Fahkahatchee and Fahka Union Bays.

Coring

Three cores were analyzed for organic and inorganic fractions. The cores were taken at sediment Stations 6 and 14 in Fahka Union Bay, and the third at Station 14 in Fahkahatchee Bay (Figure VIII- 3). Fahka Union Bay Station 6 and Fahkahatchee Bay Station 14 were chosen because of the relatively equal organic content found in the sediment traps at these locations, 30.86 percent and 28.95 percent organic content, respectively. Fahka Union Bay Station 14 was selected as being remote to the man-made canal running through it and, therefore, generally free of any possible canal effects.

Results of the core analyses are depicted on Figure VIII-13. Below a sediment depth of 15 centimeters the cores were nearly identical in color and organic content with the organic percentage leveling off at four - six percent. However, above 15 centimeters the cores differed considerably.

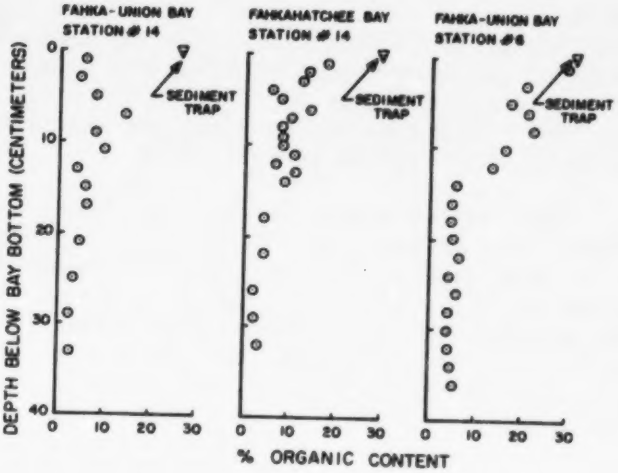

Figure VIII-13. Organic Content of Bay Bottom Cores.

The organic content of Fahka Union Bay core 6 was much greater than Fahkahatchee Bay core 14 above 15 centimeters even though the organic content of the sediment traps at these two locations was nearly equal. The Fahka Union Bay core had much slower organic degradation and also showed a possible disruption in the zone from 10 to 14 centimeters.

The core taken at Fahka Union Bay Station 14 (remote to the canal) revealed very little organic content. Possibly, sediments at this site were quickly being resuspended and transported away from the site. This is suggested by the vast difference of the organic content of the sediment trap (26 percent) and the organic content of the first centimeter of the sediment (five percent).

An unexplained phenomenon appears in all three cores at a sediment depth of three centimeters down to a depth of six centimeters. In this section of each core the organic content increased rather than decreased. Certainly a possibility is a greater abundance of infaunal organisms existing in this zone.

DISCUSSION

Fahkahatchee and Fahka Union Bays revealed few surprises, having predominantly mud bottoms blending frequently with somewhat more sandy bottoms. Oyster bars overlay these bottoms in several locations in both bays. Fahka Union Bay bottoms had a larger percentage of total area composed of mud and shell than Fahkahatchee Bay bottoms.

Sedimentation traps revealed seasonal variations in organic content of the sedimenting material, over the sampling period of July 17 - November 20, 1972, with peak organic fractions occurring in early to mid-October. During this period, decomposing periphyton was observed floating in the bays, thus obviously contributing to the organic content of the sediment.

Sedimentation rates from the traps coupled with sediment density revealed deposition rates of 2.31 cm/yr and 2.94 cm/yr for Fahkahatchee and Fahka Union Bays, respectively. These numbers being unrealistically high lead to the belief that resuspension of bottom sediments is occurring in the shallow bays.

Water column depth seems to correlate well with the inverse of the sedimentation rate. Mean daylight hour tidal depths decreased seasonably over the sampling period during which time the sedimentation rate increased. Also, the ratio of the trap depths in Fahka Union Bay to the trap depths in Fahkahatchee is relatively the same as the inverse of the ratios of sedimentation rates in the bays. Fahka Union Bay being the more shallow of the two was more susceptible to wind induced turbulence.

The limited number of cores that were taken did not yield any conclusive differences in the bays. The top 15 centimeters of the cores had wide ranges in percent organic content; however, below 15 centimeters all of the cores revealed relatively equal organic content. All cores disclosed a zone where the organic content increased with depth. Possibly, macro-organisms could have caused this irregularity. This zone was approximately three centimeters below the surface.

IX. DETRITAL TRANSPORT

INTRODUCTION

Detritus in estuary systems is a chief energy link between salt marshes and bays below them fronting the ocean. Carbon containing detritus in various forms of decomposition is carried into the bays via tidal creeks which meander through the salt marshes. During periods of high freshwater runoff these tidal creeks serve as "catch basins" to funnel the detrital load into the bay systems. During periods of low runoff they serve to carry tidal water which cyclically flushes a portion of the salt marsh.

Six major aspects of the detrital transport and decomposition scheme were investigated during this study: 1) the chemical and physical makeup of the detrital material; 2) the concentrations and quantities of detritus, total organic carbon (TOC) and tannin and lignin "like" compounds that were imported to and exported from the estuarine system; 3) the interchanging of carbon forms (detritus, TOC, tannin and lignin) as they interacted and were acted upon in the system; 4) standing crop of zooplankton and phytoplankton; 5) seasonal variations in carbon transport dynamics; and 6) a mass balance of carbon for Fahkahatchee Bay.

METHODS

In order to obtain an estimate of the detrital (including TOC and tannin and lignin) transport mechanism and rate, six sampling stations were established in the salt marsh and bay systems. Four of these sites were in Fahkahatchee Bay and two sites in Fahka Union Bay (Figure IX-1). Half of the stations were located at the interfaces between the saltmarsh and the bays and the ramaining three stations were at the interfaces of the bays and the Gulf of Mexico. Within the time limitations of the detrital study these six stations were felt to be reasonably representative of the detrital transport dynamics.

A sampling scheme was devised such that a two man boat crew could alternately draw samples from two stations over a 12 hour tidal period starting at either high or low slack water. The sampling procedure which follows required approximately 30 minutes on station. While anchored on station at mid-channel a submersible pump was employed to pump 300 liters, as measured by 100 liter containers, of tidal water through two stacked sieves. An integrated sample of the water column was obtained by varying the elevation of the pump inlet (2.54 cm I.D.). The detrital material remaining on the two sieves, U. S. Std. #50 and #230 (297 micron and 63 micron) was then transferred to labeled containers and returned to the laboratory for analysis. From the filtrate which passed through the sieves a two liter sample was taken for analysis of the more soluble constituents.

Several times during each pumping period, a ducted current meter was used to measure the mid-channel velocity profile. These velocity measurements coupled with channel cross sectional characteristics and tidal stages enabled flow quantities to be computed as described earlier in the "circulation pattern section" of Chapter VII.

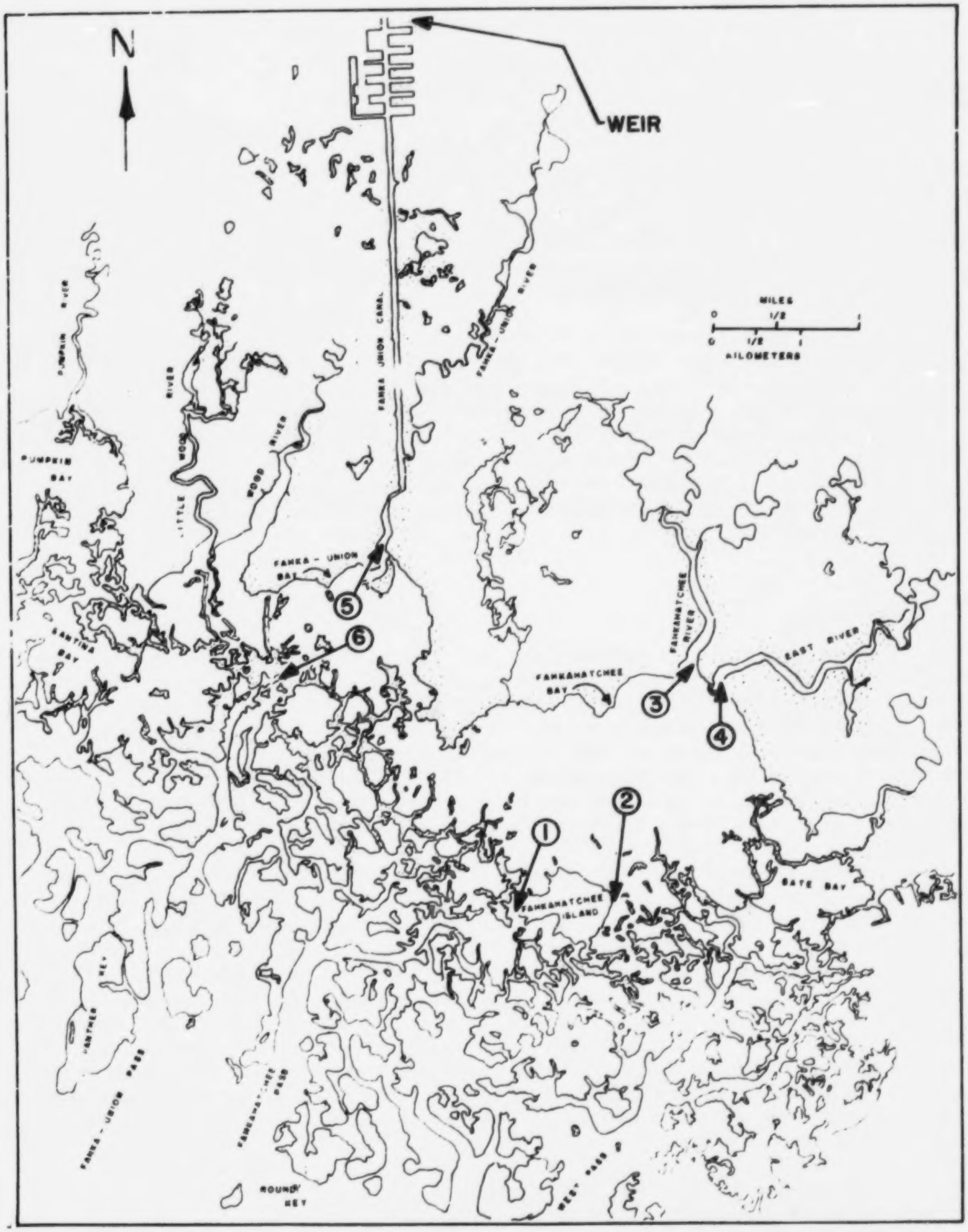
N
WEIR
MILES
0
1/2
1
0
1/2
1
KILOMETERS
PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAHKA UNION CANAL
FAHKA - UNION RIVER
FAHKA - UNION BAY
SANTINA BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
PANTHER KEY
FAHKA - UNION PASS
FAHKAHATCHEE PASS
ROUND KEY
WEST PASS
①
②
③
④
⑤
⑥

Figure IX-1. Detrital sampling stations in Fahkahatchee and Fahka Union Bays.

Analysis of the samples returned to the laboratory followed American Public Health Association Standard Methods procedures. The detrital fractions that remained on the two sieves were analyzed for ash free dry weight. A third detrital fraction was obtained by passing one liter of the before mentioned two liter filtrate sample, through an 0.8 micron millipore filter. Ash free dry weight analysis was subsequently carried out on this nanno fraction.

Subsamples for tannin and lignin and total organic carbon (TOC) analysis were taken from the two liter filtrate sample. The TOC analysis was performed using a mass spectrometer by the Chemical Services Branch, EPA, Athens, Georgia.

Phytoplankton concentrations were determined for two size fractions of the filterable material. The larger of the sizes being the material that passed through the 297 micro sieve and was retained on the 63 micron sieve. The smaller being the fraction that passed through the 63 micron sieve and was retained on a 0.8 micron filter.

Zooplankton concentrations were also broken down into two size ranges. The larger being the material that remained on the 297 micron sieve and the smaller being the material that passed through and was retained on the 63 micron sieve.

Plankton concentrations were volumetrically determined by the Sedgwick-Rafter method and reported as mg/l on a wet weight basis.

RESULTS AND DISCUSSION

Detrital sampling was rigorously conducted at two periods when the amplitudes of consecutive high or low tides were relatively equal. Nearly 400 separate analyses were performed for each period. The first period was July 18-20, 1972, during which time two stations were sampled each day. The second period was October 17-18, 1972, with the two Fahka Union Bay stations sampled on the 17th and the four Fahkahatchee Bay stations sampled on the 18th using two boats. A two man boat crew was able to make approximately eight sampling runs on each of the two stations over a 12 hour tidal cycle. Figure IX-2 presents a typical sampling regime during which time the beginning and ending high slack tides were of relatively equal amplitudes.

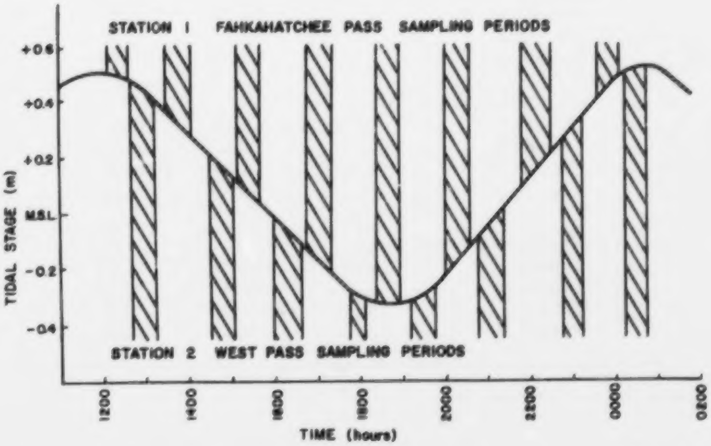

Figure IX-2. Typical 12 hour tidal cycle showing detrital sampling periods.

The July sampling period was chosen as being typical of the summer conditions and at a time when freshwater runoff should have been maximizing the "flushing" of the uplands and the salt marshes. However, as discussed in Chapter VII, upland runoff was small at this time. The October sampling was preceded by a detailed circulation study (reference made earlier) in Fahkahatchee Bay. Tidal amplitudes during the circulation study and during the October detritus study were of the same magnitude and the runoff conditions were unchanged. Therefore, the circulation patterns could be applied to the detrital load to compute mass balance in Fahkahatchee Bay.

Table IX-1 presents a summary of the average concentrations of TOC, tannin and lignin "like" compounds, and three detrital fractions for each of the six stations. Average concentrations shown are for both ebbing and flooding tides during the sampling periods in July and October.

Table IX-1. Summary of detrital concentrations sampled during ebb and flood tides in Fahka Union and Fahkahatchee Bays during July and October 1972.

					Average Concentration in mg/l			
Station	Location	Date (1972)	TOC (mg/l)	Tannin and Lignin (mg/l)	297μ+ Detrital Fraction[a]	b	297μ - 63μ Detrital Fraction[a]	63μ - 0.8μ Detrital Fraction[a]
1	Fahkahatchee Pass							
	Ebbing Tide	July 19	10.50	0.45	0.54		0.50	9.10
	Flooding Tide		11.71	0.47	0.14		0.13	4.69
	Ebbing Tide	Oct 18	8.0	0.39		0.10		1.58
	Flooding Tide		7.67	0.32		0.40		2.30
2	West Pass							
	Ebbing	July 19	12.25	0.47	0.44		0.50	7.76
	Flooding		15.44	0.42	0.15		0.15	2.18
	Ebbing	Oct 18	8.40	0.47		0.092		3.12
	Flooding		7.75	0.37		0.248		2.48
3	Fahkahatchee River							
	Ebbing	July 18	17.50	1.09	0.27		0.22	9.47
	Flooding		18.76	1.62	0.18		0.36	20.06
	Ebbing	Oct 18	11.67	0.96	0.45		0.43	3.47
	Flooding		12.00	0.91	0.21		0.18	2.37
4	East River							
	Ebbing	July 18	20.50	1.62	0.23		0.21	14.24
	Flooding		23.67	1.97	0.12		0.22	14.26
	Ebbing	Oct 18	13.22	1.18	0.42		0.52	2.90
	Flooding		12.25	1.11	0.27		0.17	1.65
5	Fahka Union North							
	Ebbing	July 20	15.00	0.83	0.24		0.41	6.21
	Flooding		14.66	0.88	0.35		0.32	7.88
	Ebbing	Oct 17	9.83	0.74	0.49		0.31	2.60
	Flooding		9.33	0.62	1.69		0.49	1.40
6	Fahka Union South							
	Ebbing	July 20	14.80	0.69	0.17		0.37	7.90
	Flooding		16.43	0.51	0.33		0.19	3.76
	Ebbing	Oct 17	9.20	0.46	0.34		0.31	4.08
	Flooding		7.40	0.44	0.26		0.23	4.76

a Ash free dry weight

b Combination of 297μ+ detrital fraction and 297μ - 63μ detrital fraction

Odum and de la Cruz (1967) reported detrital fractions in the ratio of 1, 4, and 95 for material retained on 239 micron, 63 micron, and 0.8 micron filters, respectively. They were measuring detrital transport off a spartina salt marsh near Sapelo Island in Georgia. The ratio of the detrital size fractions shown in Table IX-1 is 5, 4, and 91 with relatively the same size regime as the Georgia study. Obviously then, the predonderance of the detrital material carried in the tidal waters in both studies was in a highly fractionated state. This is further evidenced by the TOC concentrations which were greater than the detrital sieved fractions. TOC analyses in this study represents carbon which passed through a 63 micron sieve.

Ebbing tide average detrital concentrations (July and October) of TOC, tannin and lignins, and detrital fractions are presented in Figures IX-3, 4 and 5, respectively. All six stations are shown with their average ebb tide concentrations for July and October.

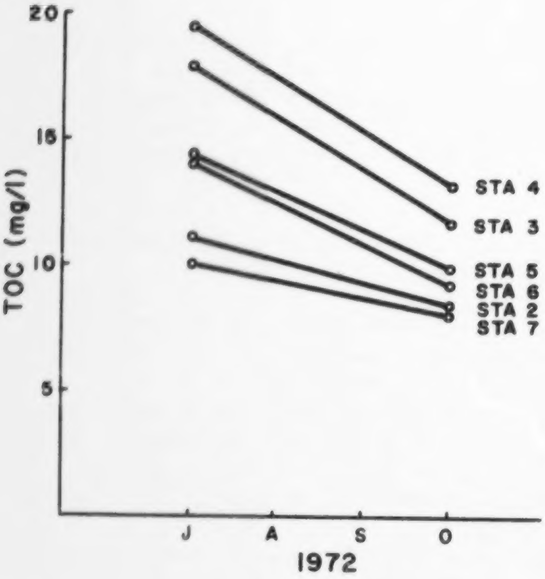

Figure IX-3. Average ebb tide TOC concentration at the six sampling stations in July and October 1972.

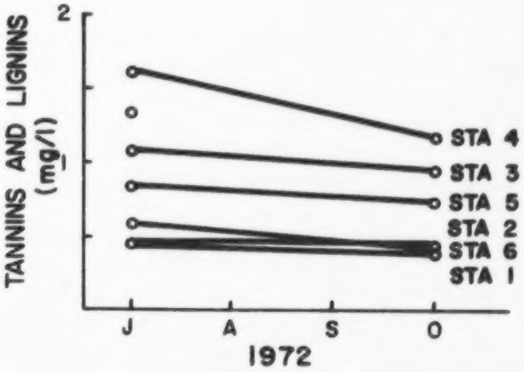

Figure IX-4. Average ebb tide tannin and lignins concentration at the six sampling stations in July and October 1972.

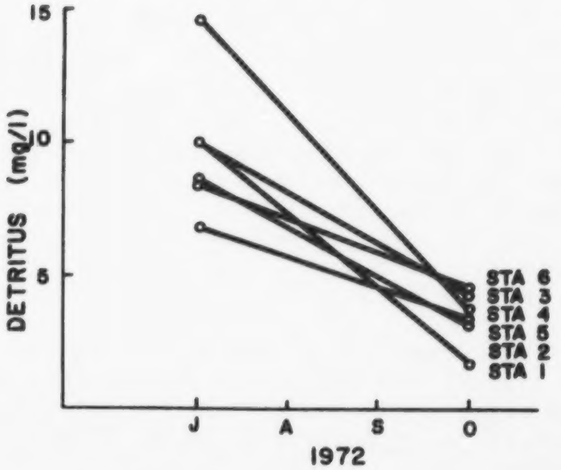

Figure IX-5. Average ebb tide detrital concentration at the six sampling stations in July and October 1972.

A comparison of ebb tide TOC concentrations at the rivers to those at the passes in each bay reveal that concentration gradients across Fahkahatchee Bay (Stations 3 to 1) are much greater than those seen in Fahka Union Bay (Stations 5 to 6). TOC concentrations decreased 37 percent from salt marsh/bay interface (rivers) to bay/Gulf interface (passes) in Fahkahatchee Bay while in Fahka Union Bay the TOC concentration decrease was only four percent. This may be due to several complexities such as: 1) flow "short circuiting" in Fahka Union Bay, due to the relatively deep Fahka Union Canal; 2) upland flows based upon flow/bay area differ considerably between the bays; 3) fractionization of detritus into more soluble forms of carbon.

Short circuiting of tidal waters through Fahka Union Bay can easily occur due to the open channel characteristics found in that bay. At mean tide the average depth of the canal at mid-bay is three times greater than the average depth of the bay. Fahkahatchee Bay has no such channels (see Figures VII-28 and VII-29). Short circuiting via Fahka Union Canal is also seen in the salinity patterns reported in Figures VII-45 through VII-56. In particular, Figures VII-51, VII-54, and VII-55 reveal strong convergents of isohalines near the Fahka Union Canal.

The second factor involves considerations of the bay dilution of in-flowing concentrations of detritus.

In October, during ebb tides, the flow passing into Fahka Union Bay past Station 5 was 1,765 X 10^6 liters or 9.5 X 10^6 liters/hectare based upon the surface area of the bay at MSL. While in Fahkahatchee Bay the flow passing into the bay via Fahkahatchee and East Rivers was only 386 X 10^6 liters or 0.5 X 10^6 liters/hectare. Fahkahatchee Bay thus has a greater diluting capacity for upstream flows than does Fahka Union Bay.

The third complexity, transformation of carbon forms, will be discussed later in this section.

TOC and detrital mass flow computations reveal vast differences of carbon transport into the two bays in terms of mass per unit area of bay. During the sampled ebb tide in July the mass of TOC entering Fahkahatchee Bay via the two tidal rivers was 25,600 kg or 34.6 kg/ha based on the bay surface area at MSL. In October, this value decreased to 6.7 kg/ha while in Fahka Union Bay on an ebb tide the Fahka Union Canal discharged 75.8 kg/ha and 93.3 kg/ha of TOC into the bay in July and October, respectively. Therefore, again on an area basis, Fahka Union Bay received 2.2 times the mass/area and 13.9 times the mass/area as did Fahkahatchee Bay during ebb tides in July and October, respectively.

Detrital inputs from the tidal rivers in Fahkahatchee Bay during ebb tides were 23.5 kg/ha and 2.1 kg/ha for July and October, respectively. In Fahka Union Bay the detrital inputs during the ebb tides were 34.7 kg/ha and 32.2 kg/ha for July and October. Therefore, on an area basis Fahka Union Bay received 1.5 and 15.3 times the mass/area as did Fahkahatchee Bay in the July and October sampling periods. However, the above comparisons must be tempered by the fact that much of the flow into and out of Fahka Union Bay stays within the channel and does not mix with the water in the bay

Mass transport of the three chemical parameters (TOC, detritus, and tannin and lignin) into and out of Fahkahatchee Bay was computed from concentrations, flow measurements and circulation relationships. Table IX-2 reveals only mass transport of each chemical parameter since the chemical analyses overlap one another.

Table IX-2. Fahkahatchee Bay mass transport of three chemical parameters found in one tidal cycle in October 1972.

Chemical Parameter	Net Transport[a] Via the Rivers		Net Transport[a] Via the Passes		Net Bay Balance	
	Import	Export	Import	Export	Deposition	Export
TOC	3806 kg			6588 kg		2782 kg
Tannins and Lignins	396			782		386
Detritus	4431		855		5286	

[a] Net Transport to the Bay

It is apparent that Fahkahatchee Bay is quite a dynamic system with TOC and tannin and lignin analysis showing production and detritus analysis showing deposition in the bay (Table IX-2). Tannins and lignins being degradation products of woody plants cannot be produced in the bay system other than from the mangrove islands. However, woody plant fragments deposited in the bay as detrital fractions can undergo decomposition into tannins and lignins and other carbon bearing compounds.

In order to arrive at a true carbon mass balance for the October tidal cycle in Fahkahatchee Bay the carbon forms must be adjusted due to overlapping in their chemical and physical makeup. The TOC analyses reports concentrations of organic carbon compounds ranging from soluble form to 63 microns in size. The detrital fractions analyzed were, in decreasing order of size: 1) that which remained on the 297 micron sieve; 2) that which passed through the 297 micron sieve and remained on the 63 micron sieve, and 3) that which passed through the 63 micron sieve and remained on a 0.8 micron millipore filter. Clearly then the TOC analyses contains carbon forms also found in the third form above. Secondly, a conversion factor is required to convert detritus concentrations (ash free dry weight) to equivalent carbon concentrations. This is accomplished by assuming an empirical formula of CH_2O (40 percent carbon) for detritus. The carbon mass balance for Fahkahatchee Bay is presented in Table IX-3.

The tidal rivers yielded large quantities of carbon (Table IX-3) to Fahkahatchee Bay in October. Most of the material was in carbon forms of less than 0.8 micron in size with a significant quantity in the size range of 0.8 to 63 microns and with some forms existing above 63 microns in size. However, when the tidal water exits the bay via the passes to the Gulf nearly all (98 percent) of the organic carbon was contained in the 0.8 micron or less fraction. Thus, large quantities of detrital material were deposited in the bay and then converted - broken down - into smaller fractions and to more soluble forms before being exported from the bay.

Table IX-3. Fahkahatchee Bay carbon mass balance for one tidal cycle in October 1972.

Carbon fraction size range	Net transport [a] via the rivers		Net transport [a] via the passes		Net bay balance	
	Import	Export	Import	Export	Deposition	Export
Soluble thru 0.8 micron [b]	2864			6380		3516
0.8 micron thru 63 micron [c]	1282			127	1155	
63 micron and larger [d]	222		213		435	
Net carbon	4368 kg			6294 kg		1926 kg

[a] Net transport to the bay

[b] By assuming an empirical formula of CH_2O (40 percent carbon) for detritus this fraction is computed from: TOC - (0.40 X (0.8 to 63μ fraction));

[c] 0.40 X (0.8 to 63μ fraction);

[d] 0.40 X (63 - 297μ and 297μ + fractions).

The above degradation process can be further amplified by again referring to the bay circulation pattern study, in particular the bay turnover rates on page VII-46. From this figure, of an initial concentration entering the bay in a soluble form, 10 percent will be remaining after 42 tidal cycles, or 21 days (Figure VII-40). From this same figure the half-life of the concentration is 13 cycles. Therefore, after six days, 50 percent of an initial concentration would be remaining in the bay available for microbal degradation and detrital feeders. Since a large portion of the detrital material entering the bay was not in a soluble form, the half-life, due to flushing would be greater than six days.

Along with the fractionation of the organic material there appears to be net carbon production taking place in the bay itself. Evidenced by a net carbon export from the bay of 1,926 kg per tidal cycle or 3,852 kg/day. Based upon the surface area of Fahkahatchee Bay at MSL the net production of carbon was 0.5 $gm/m^2/day$.

Table IX-4 presents a summary of the phytoplankton and zooplankton concentrations found in the tidal waters at the six sampling stations. Plankton samples were taken both in the July and October study. However, due to time limitations only the July samples were analyzed.

No clearcut trends are apparent in the phytoplankton results. A concentration range of 0.066 to 5.166 mg/l was found in Fahkahatchee Bay while in Fahka Union Bay the range was only 0.136 to 2.626 mg/l. Little significance can be derived from these ranges other than the fact that phytoplankton

Table IX-4. Summary of phytoplankton and zooplankton concentrations in mg/l (wet weight basis) found in detrital fractions during mid-July in Fahkahatchee and Fahka Union Bays.

Station	Location	Phytoplankton*	Zooplankton	
		297μ - 0.8μ	297μ	297μ - 63μ
1	Fahkahatchee Pass			
	Ebbing tide	0.066	0	0.008
	Flooding tide	0.741	0.001	0.020
2	West Pass			
	Ebbing	5.166	0	0.005
	Flooding	3.790	0	0.011
3	Fahkahatchee River			
	Ebbing	0.786	0	0.016
	Flooding	0.372	0	0.025
4	East River			
	Ebbing	0.296	0	0.005
	Flooding	0.961	0.007	0.006
5	Fahka Union North			
	Ebbing	0.136	0	0.003
	Flooding	2.626	0	0.002
6	Fahka Union South			
	Ebbing	0.447	0	0.007
	Flooding	1.402	0	0.008

* Combined sample from 297 - 63 micron and 63 - 0.8 micron detrital fractions.

concentration at the Gulf-Bay interfaces were greater on flood tides than on ebb tides. It follows that phytoplankton concentrations were greater in the Gulf than in the bays.

Of the two detrital fractions analyzed for zooplankton concentrations the larger fraction (297 micron and greater) contained essentially no zooplankton. However, the smaller detrital fraction (297 - 63 micron) did contain zooplankton concentrations, but only at level of a few micrograms/liter. Two points are apparent from the zooplankton concentrations found in the 297 - 63 micron seston In general, zooplankton concentrations found in Fahkahatchee Bay were greater than those found in Fahka Union Bay. Evidenced by unweighted concentration averages of 0.024 mg/l for the four stations in Fahkahatchee Bay and 0.010 mg/l for the two stations in Fahka Union Bay, the above is based upon all observations (flooding and ebbing tides) at the six stations.

Secondly, zooplankton concentrations on flooding tides were greater than those for ebbing tides, therefore producing a concentration gradient seaward from the salt marshes.

Tables IX-5 and IX-6 are presented as further evidence that plankton concentrations were not abundant in either Fahkahatchee or Fahka Union Bay.

Table IX-5.[1] Zooplankton concentrations found in Fahka Union Bay as sampled with a 500 micron mesh plankton net.

Date	Concentration PPM
May 16, 1971	0
August 2, 1971	0
November 1, 1971	0.006
February 14, 1972	0

(1) Gulf Coastal Fisheries Center, St. Petersburg, Florida

Table IX-6. Phytoplankton collected on June 15, 1972, with a 500 micron mesh plankton net.

Station	Algae	Diatoms
Fahkahatchee Bay		
Fahkahatchee River	0 c/ml	104 c/ml
East River	0	44
Fahkahatchee Pass	6	358
West Pass	0	264
Fahka Union Bay		
Fahka Union Canal	0	29
Fahka Union Bay	0	201

X. WATER CHEMISTRY

INTRODUCTION

Water plays a dominant role in the life cycle, function, and diversity of all animal species found in south Florida. The chemical characteristics of water regulates and is regulated by the biota. It therefore follows that this study would not be complete until the chemical characteristics were evaluated.

The study area is not completely unaffected by man. There are many hunting camps within the area; some of the water entering the study area originates from farmlands where fertilizers and pesticides have been used; and many canals have been dug, draining surface and ground water from the surrounding lands. Despite these intrusions there are still sections within the study area where only minor effects of man may be observed.

Data obtained from this study will be used to show areas where degradation of the environment is taking place, as background information for future studies and for the suitability of this area for a particular use or multipurpose uses.

METHODS

During November 1971, 16 sampling stations were established (Figures X-1 and 2). These stations were selected as being representative of the aquatic area and for determining any changes in water chemistry within the drainage system. Location and description of each station are presented in Appendix E.

Stations 1, 2, and 3 were selected to determine the chemistry of water entering the study area; Stations 4, 5, 6, 7 and 10 were selected to determine the chemical characteristics of the fresh water in the study area; Stations 3, 4, and 10 were also selected to determine the chemical characteristics of water in man-made canals; Stations 8 and 9 were selected to determine the general chemical features of water at the freshwater-salt marsh interface; Stations FU-1 and F-1 were selected to determine the chemical characteristics of water entering the Fahka Union and Fahkahatchee Bay, respectively; Stations FU-2 and FU-3 were selected to determine the chemical characteristics of water in an "unnatural" bay system (Fahka Union Bay system), which receives most of its water from a man-made canal (Fahka Union Canal); and Stations F-1 and F-2 were selected to determine the chemical characteristics of water in a "natural" bay system (Fahkahatchee Bay system), which receives its water from natural drainage.

Sampling and analyses were initiated in December 1971 and continued through December 1972. The type, frequency, and location of analyses are presented in Table X-1. In addition to the above samples, weekly samples were taken at Stations 4 and 10 and monthly samples were taken at Stations 5, 6, and 7 to determine the nutrients transported by water from the uplands into the estuaries.

Except for dissolved oxygen determination, grab samples were taken and then transferred into clean, 2-liter, polyethylene bottles. Preservatives were added to only those samples scheduled for shipment to the Southeast Environmental Research Laboratory in Athens, Georgia. Analyses conducted in

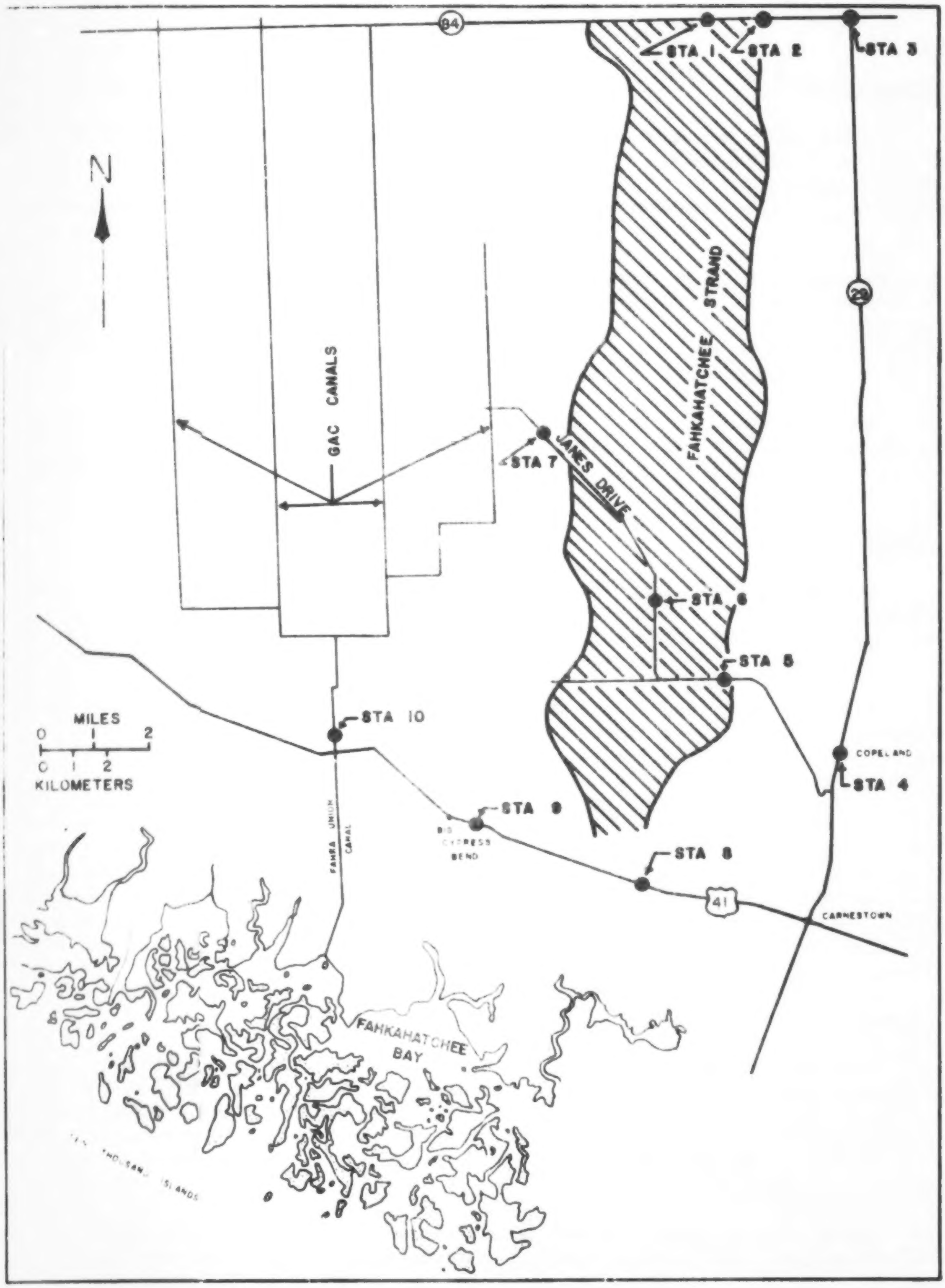
84
STA 1
STA 2
STA 3
N
29
FAHKAHATCHEE STRAND
GAC CANALS
JANES DRIVE
STA 7
STA 6
STA 5
MILES
0 1 2
0 1 2
KILOMETERS
STA 10
COPELAND
STA 4
STA 9
BIG CYPRESS BEND
FAHKA UNION CANAL
STA 8
41
CARNESTOWN
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS

Figure X-1. Location of the water quality stations.

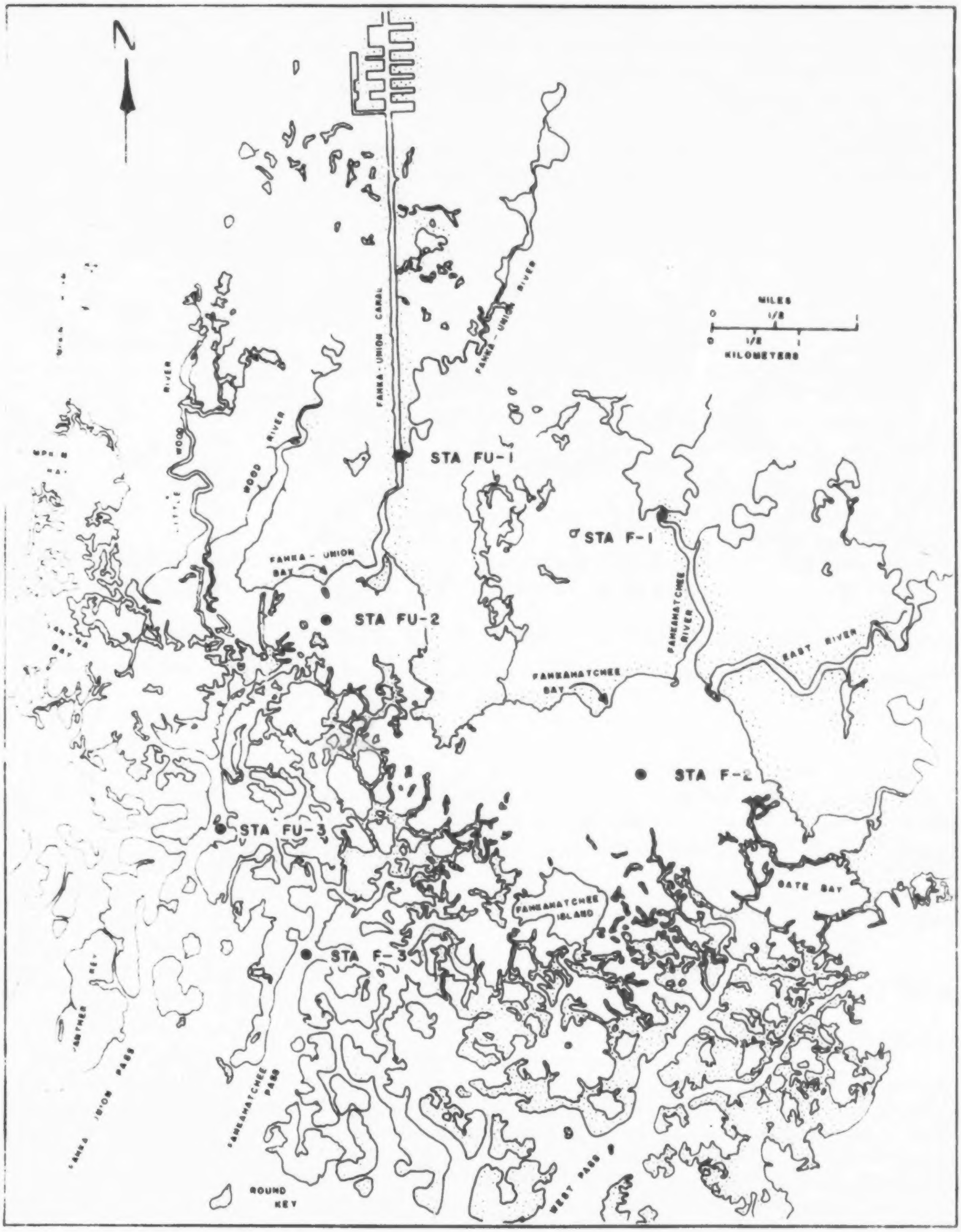
N
MILES
0
1/2
1
0
1/2
1
KILOMETERS
FAKA - UNION CANAL
FAKA - UNION RIVER
LITTLE WOOD RIVER
WOOD RIVER
STA FU-1
STA F-1
FAKA - UNION BAY
STA FU-2
FAKAHATCHEE RIVER
EAST RIVER
FAKAHATCHEE BAY
STA F-2
STA FU-3
GATE BAY
FAKAHATCHEE ISLAND
STA F-3
PANTHER KEY
FAKA - UNION PASS
FAKAHATCHEE PASS
ROUND KEY
WEST PASS

Figure X-2. Location of the water quality stations.

Table X-1. Physical and chemical analyses.

Parameter	Frequency of measurement	Where determined
Physical		
Temperature	Monthly (starting Dec., 1971)	Field
Turbidity	Monthly (starting Dec., 1971)	Naples lab
Apparent color	Monthly (Dec., 1971 to Feb., 1972)	Naples lab
Conductivity	Monthly (starting Feb., 1972)	Field
pH	Monthly (starting Dec., 1971)	Naples lab
Chemical		
Alkalinity	Monthly (starting Dec., 1971)	Naples lab
Chloride	Monthly (starting Dec., 1971)	Naples lab
Dissolved oxygen	Monthly (starting Dec., 1971)	Naples lab
Total and soluble Kjeldahl nitrogen	Monthly (starting Mar., 1972)	Naples lab
Nitrate and nitrite nitrogen	Once (August, 1972)	SERL, Athens, Ga.
Total and soluble organic carbon	Monthly (starting Mar., 1972)	SERL, Athens, Ga.
Total and soluble phosphorus	Monthly (starting Mar., 1972)	Naples lab
Sulfate	Monthly (starting Dec., 1971)	Naples lab
Tannin and lignin "like" compounds	Monthly (starting Jan., 1972)	Naples lab

the Naples laboratory were usually initiated within a few hours of sampling. All analyses except for the tannin and lignin "like" test followed one of the methods given in the EPA manual Methods for Chemical Analysis of Water and Wastes, 1971 and/or Standard Methods for the Examination of Water and Wastewater, 13th Ed. The specific test used for each parameter is presented in Appendix F. Mention of trade names or commercial products does not constitute endorsement by the Environmental Protection Agency.

RESULTS

Physical Characteristics

Apparent color values ranged from 50 to 100 at all freshwater stations except Station 10 (Fahka Union Canal), where a consistent value of 30 was found. Values found at the Fahkahatchee Strand stations are not unusual for swamp water. For marine waters, the lowest value (25) was found in Fahkahatchee and Fahka Union Bays, and the highest value (120) was found at Station F-1 which receives direct drainage from a mangrove and salt-marsh swamp. Apparent color values for each station are given in Table X-2.

Table X-2. Apparent color values for each station per month.

Station	Dec.	Jan.	Feb.	Station	Dec.	Jan.	Feb.
1	90	80	90	9	100	100	80
2	100	100	80	10	30	30	30
3	100	100	90	F-1	120	100	100
4	90	60	50	F-2	40	30	30
5	50	60	60	F-3	35	25	25
6	90	90	90	FU-1	50	45	45
7	70	60	50	FU-2	45	35	30
8	80	90	100	FU-3	30	30	25

The conductivity of the freshwater stations ranged from a high of 1.70 mmho/cm at Station 5 to a low of 0.22 mmho/cm at Station 2. The estuarine stations had their highest values during May (>60 mmho/cm) and their lowest values during September. At all stations, conductivity was found to be inversely related to rainfall. During the months of low rainfall, salt concentrations increased which causes an increase in conductivity; and during the months of high rainfall, the reverse would occur. The maximum, minimum and median values are presented in Table X-3.

Table X-3. Range and median values for conductivity in mmho/cm.

Station	Minimum	Median	Maximum	Station	Minimum	Median	Maximum
1	0.26	0.46	1.24	9	1.90	6	40
2	0.22	0.44	1.36	10	0.81	0.81	1.62
3	0.48	0.60	1.44	F-1	23	43	< 60
4	0.50	0.65	1.44	F-2	37	52	< 60
5	0.31	0.50	1.70	F-3	38	52	< 60
6	0.53	0.57	0.70	FU-1	2	35	< 60
7	0.47	0.58	0.75	FU-2	6	38	< 60
8	1.30	15	31	FU-3	35	52	< 60

Values of pH between 7 and 8 were observed at all freshwater stations during the year except for acidic readings during April at Stations 1, 2, and 3 and a reading of 8.1 at Station 10 during February. Except for a value of 8.8 found in Fakha Union Bay during November, the pH readings for both bay systems ranged from 7.6 to 8.1. Monthly variations of pH at all stations are presented in Figure X-3.

There was a definite annual trend in water temperature, with December, January, and February being the coldest months, and June, July, and August being the hottest months. The greatest temperature range occurred at Station 5 with a low of 20° C in February and a high of 35.5° C in August. Because of the greater water flow, Station 10 had the least temperature fluctuation compared to the other freshwater stations. There were no major differences in temperature between the bays. The annual trend in temperature for each station is presented in Figure X-4.

Median values of turbidity for the undeveloped strand area were very low (2.0 JTU). In areas affected by dredging and development operation, which is represented by the Fahka Union Canal and Fahka Union Bay, there was an increase in the median turbidity (72.0 JTU). The Fahka Union Bay system, which receives water from the Fahka Union Canal, had median values of 5.6 and 5.8 JTU; and at the same time, the median values for Fahkahatchee Bay system were 4.4 and 5.0 JTU. Turbidity followed no yearly trend. Maximum, minimum, and median values of turbidity for each station are presented in Figure X-5.

Chemical Quality

At most stations, a decrease in alkalinity was observed from April through June and from September through October. Mean values for the Fahka Union Canal and Barron River stations were higher than most other stations in the Strand. This is an indication of groundwater drainage into these canals, since three well stations had total alkalinity values approximately 150 percent higher than the surface water. Stations 6 and 7 were dry during the period when the other stations had their lowest values; therefore, their mean values were much higher than the other strand stations. The range and mean values for Fahka Union Bay were greater than that for Fahkahatchee Bay. These greater values indicate the influence the Fahka Union Canal discharge has on Fahka Union Bay. The maximum, minimum, and mean values are presented in Figure X-6.

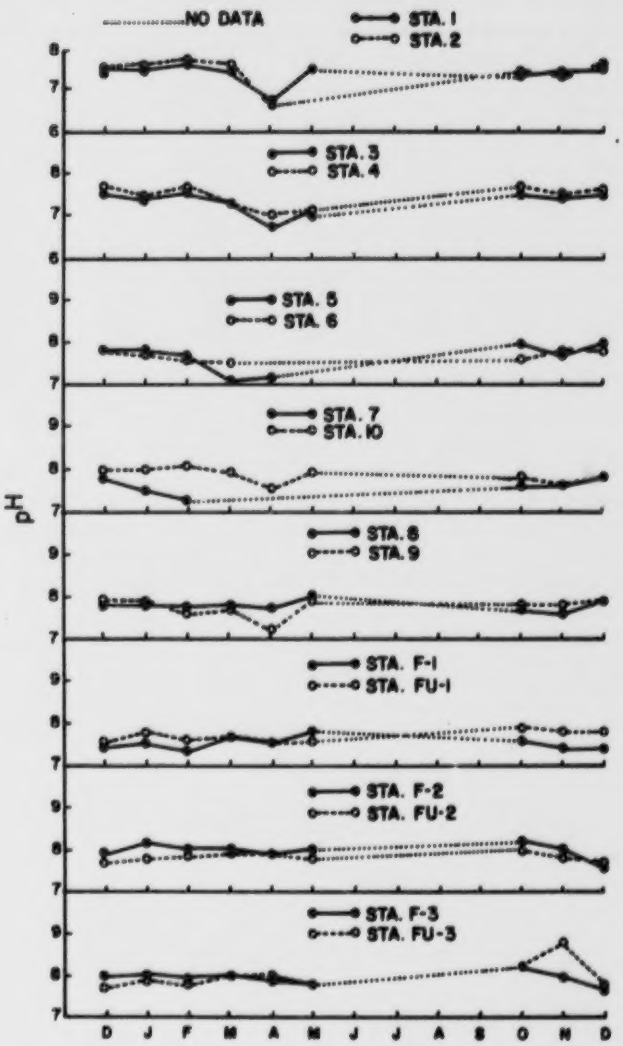

Figure X-3. pH values for each station per month.

At most stations, chloride concentrations reached a maximum during May and minimum during August through October. This trend excludes March and April, since no chloride analyses were conducted. Chloride levels varied inversely to the amount of rainfall for the year, the concentration of salts during the dry period, and the dilution of salts during the wet period. Chloride concentrations in the Fahka Union Canal at Station 10 exceeded all other freshwater stations.

The yearly mean chloride concentration of 72 mg/l at Station 10 was the result of saltwater intrusion occurring during high tides. Freshwater discharges from Fahka Union Canal effected a reduction in chloride levels in the Fahka Union Bay system. Mean chloride concentration in the Fahka Union Bay was approximately 25 percent less than reported for the Fahkahatchee Bay. The maximum, minimum, and mean values for all stations are presented in Figure X-7.

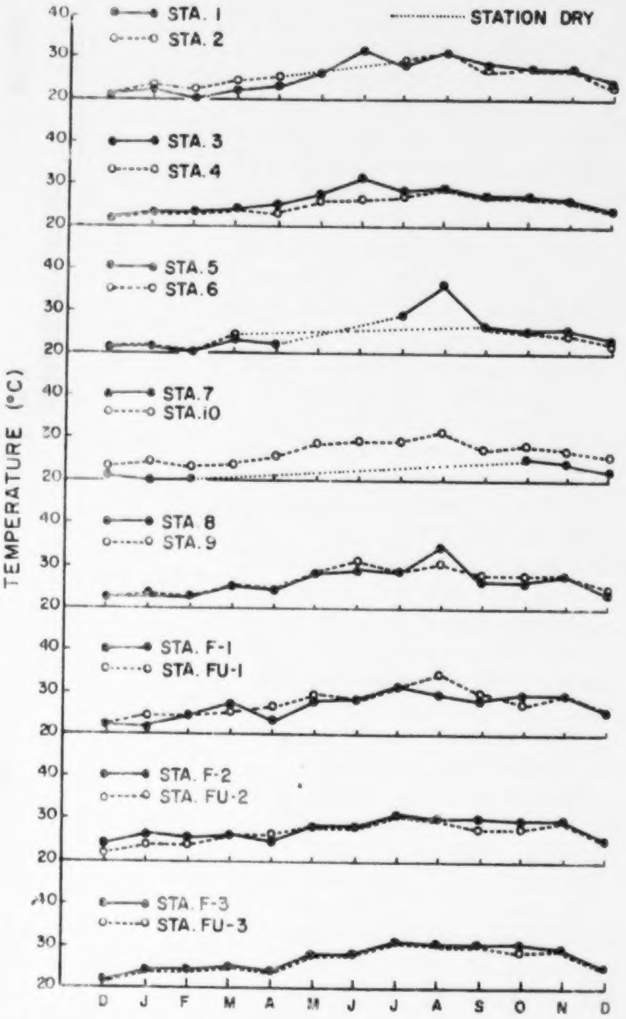

Figure X-4. Temperature values for each station per month.

Sulfate concentrations at Stations 1 through 7 ranged from below the minimum detection limit (1.0 mg/l) to a maximum of 9.7 mg/l. During May for the freshwater stations and March to May for the estuarine stations, no sulfate analysis was conducted. A major difference occurred between the sulfate concentrations at Station 10 and the other freshwater stations. Here again, this was mainly due to the intrusion of salt water during high tides. As with the chloride values, the drainage of the Fahka Union Canal into the Fahka Union Bay was reflected in the lower maximum and mean values for the bay compared to the Fahkahatchee Bay. Sulfate concentrations were nearly 25 percent less in Fahka Union Bay. The maximum, minimum, and mean values for each station are presented in Table X-4. In calculating the mean, all values less than the minimum detection limit was treated as zero.

At all stations except 6 and 7, the highest dissolved oxygen concentrations were found during March through June. Concentrations at some stations reached super-saturation during this period (Stations 10 and F-2 during March; Stations 10, F-2, F-3, FU-2, FU-3 during April; and Stations 10, F-2, FU-2 during May). This was attributed to increased plant metabolic activity. The highest concentrations were found at Station 10 during April and Station F-2 during May, with values of 9.8 and 10 mg/l respectively. The lowest concentrations at most stations were found during September and October, with Stations 2 and F-1 having concentrations (<0.50) below the minimum detection limit. During most of the year, oxygen concentrations in the strand water were well below saturation (usually between 1 and 3 mg/l). The abundance of aquatic vegetation and the high rate of flow were the main cause for near- and super-saturation concentrations at Station 10 during most of the year. The drainage of salt-marsh water was the main cause for low mean value for Station F-1 compared to mean values at the other estuarine stations. No major difference was found in dissolved oxygen levels between the bays. Most dissolved oxygen samples were taken between 1000 and 1500 hours, which biased the results toward the high side. The maximum, minimum, and mean values are presented in Figure X-8.

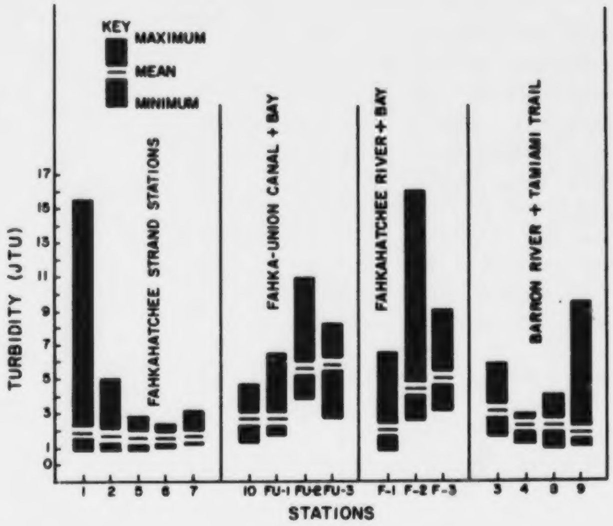

Figure X-5. The median and range values for turbidity.

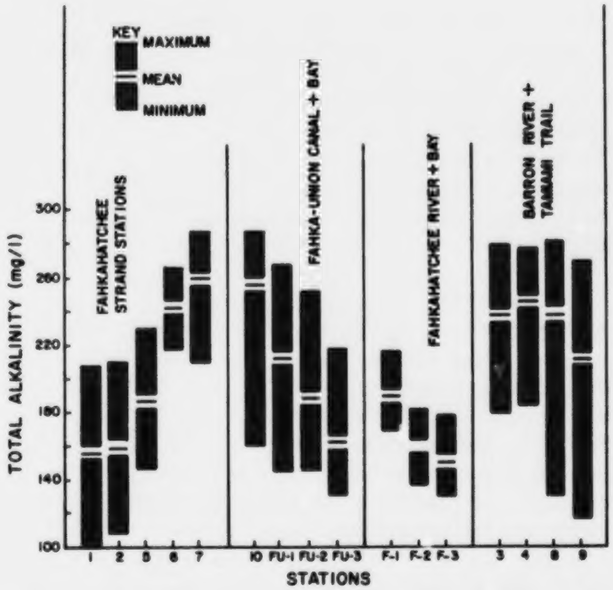

Figure X-6. The mean and range values for total alkalinity.

A general increase in the concentrations of tannin and lignin "like" compounds at all stations occurred from June through November due to flushing of upland swamps during periods of heavy rainfall. Concentrations in the strand ranged from 0.6 to 2.8 mg/l. Runoff from marshlands caused the high mean concentrations at Stations 8, 9 and F-1. The decrease in mean concentrations (1.7 mg/l to 0.4 mg/l) between Stations F-1 and F-2 indicates the rapid degradation of these compounds in an environment exposed to long periods of sunlight and high dissolved oxygen levels. There were no apparent differences in mean concentrations between the bays. The maximum, minimum, and mean values for each station are presented in Figure X-9.

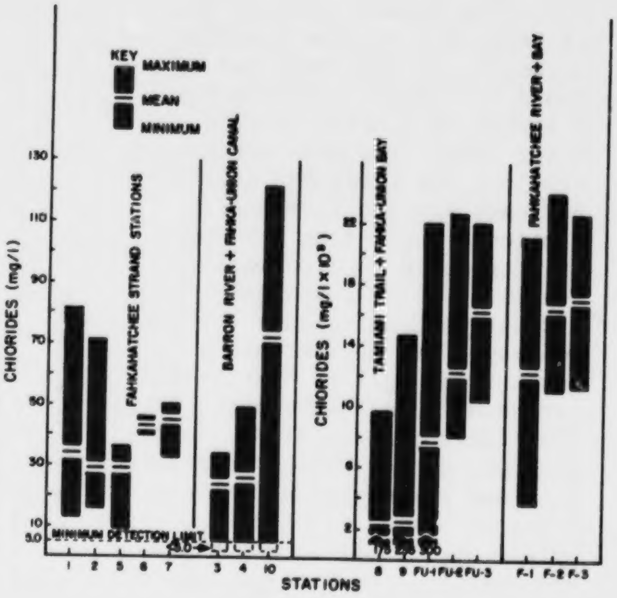

Figure X-7. The mean and range values for chlorides.

Table X-4. Range and mean values for sulfates in mg/l.

Station	Minimum	Mean	Maximum	Station	Minimum	Mean	Maximum
1	<1.0	2.1	7.6	9	8.2	251	1,420
2	<1.0	2.9	9.7	10	11.2	43.9	74
3	<1.0	3.2	9.4	F-1	510	1,570	2,360
4	<1.0	2.0	4.3	F-2	1,060	1,960	3,020
5	<1.0	1.5	5.2	F-3	1,230	2,130	3,120
6	<1.0	1.0	5.0	FU-1	84.3	878	2,160
7	<1.0	1.4	4.5	FU-2	161	1,490	2,760
8	5.0	221	900	FU-3	960	1,980	2,940

One set of samples for NO_2-NO_3 nitrogen values was taken in August. No significant concentrations were found at any station. The highest concentrations of 0.03 and 0.08 mg/l were found on Barron River at Stations 3 and 4 respectively. Most stations had concentrations less than the minimum detection limit (0.01 mg/l). Stations 6 and 7 were dry during this period; therefore, no samples were taken. The concentration for each station is given in Table X-5.

The highest concentration of total and soluble Kjeldahl nitrogen was 6.80 mg/l and was found at Station 1 during May, a period of minimum surface water flow. The mean concentrations for total Kjeldahl nitrogen for the freshwater stations ranged from 0.56 mg/l at Station 10 to 1.66 mg/l at Station 1. Total Kjeldahl nitrogen concentrations for the two bays were approximately equal (0.36 mg/l at Station F-2 versus 0.43 mg/l at Station FU-2). The higher mean total Kjeldahl nitrogen concentration at Stations 8, 9 and F-1 compared to the other estuarine stations was mainly due to direct marshland drainage. In most cases, the soluble fraction of total Kjeldahl nitrogen represented from 80 to 90 percent of the total Kjeldahl nitrogen. The percent of total soluble Kjeldahl nitrogen was less in Fahka Union Bay than in Fahkahatchee Bay. The maximum, minimum, and mean concentrations for each station are shown in Figure X-10. In calculating the mean, all values less than the minimum detection limit (0.06 mg/l) were treated as zero. The percentage of the total Kjeldahl nitrogen reported as total soluble Kjeldahl nitrogen for each station is presented in Table X-6.

Sporadically throughout the year, the total phosphorus concentration in most areas fell below the minimum detection limit (0.02 mg/l). The highest concentration of 0.40 mg/l was found at Station 9 during April, a period of minimum flow. Mean concentrations for total phosphorus for all stations ranged from 0.02 to 0.08 mg/l, with Station 1 having the highest mean concentration.

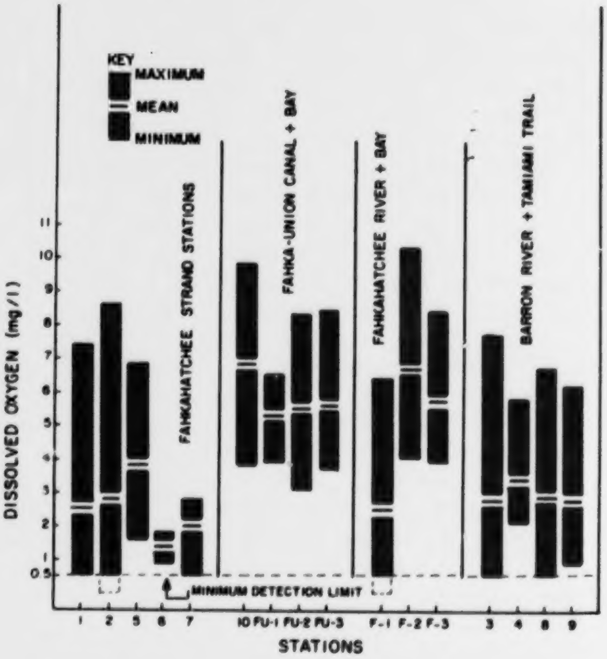

Figure X-8. The mean and range for dissolved oxygen.

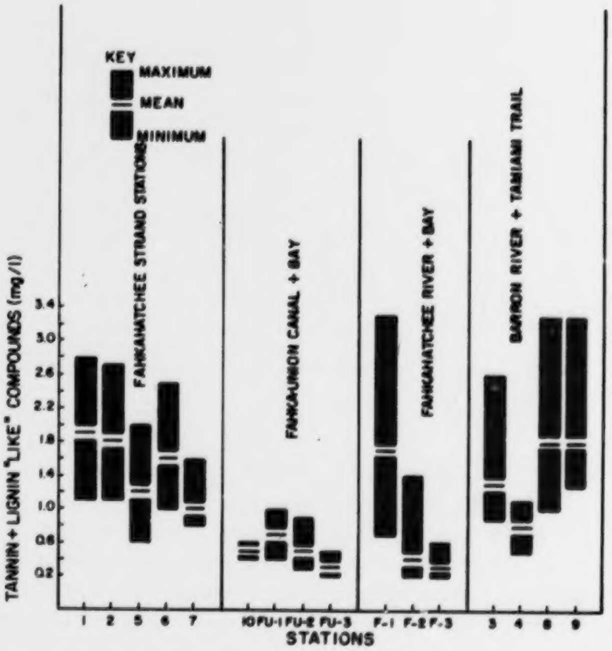

Figure X-9. The mean and range values for tannin and lignin "like" compounds.

Table X-5. Nitrate and nitrite nitrogen concentrations for the month of August 1972 in mg/l.

Station	NO_3-NO_2 nitrogen	Station	NO_3-NO_2 nitrogen
1	<0.01*	9	0.01
2	0.01	10	<0.01
3	0.03	F-1	<0.01
4	0.08	F-2	<0.01
5	<0.01	F-3	<0.01
6	**	FU-1	0.01
7	**	FU-2	<0.01
8	<0.01	FU-3	<0.01

* Less than the minimum detection limit of 0.01 mg/l.
** Stations were dry.

Mean concentrations for the Fahkahatchee Strand stations were much higher than the mean concentration in the Fahka Union Canal (Station 10). Mean concentrations in the strand ranged from 0.04 to 0.08 mg/l, compared to 0.02 mg/l at Station 10. The Fahka Union Bay maintained a lower mean concentration of total phosphorus than did Fahkahatchee Bay. Less than 50 percent of the total phosphorus was in the soluble form at all stations except Stations F-1 and FU-3, where it was 60 percent. The maximum, minimum, and mean concentrations for each station are presented in Figure X-11. In calculating the mean, all values less than the minimum detection limit (0.02 mg/l) were treated as zero. The percentage of total phosphorus reported as total soluble phosphorus for each station is presented in Table X-7.

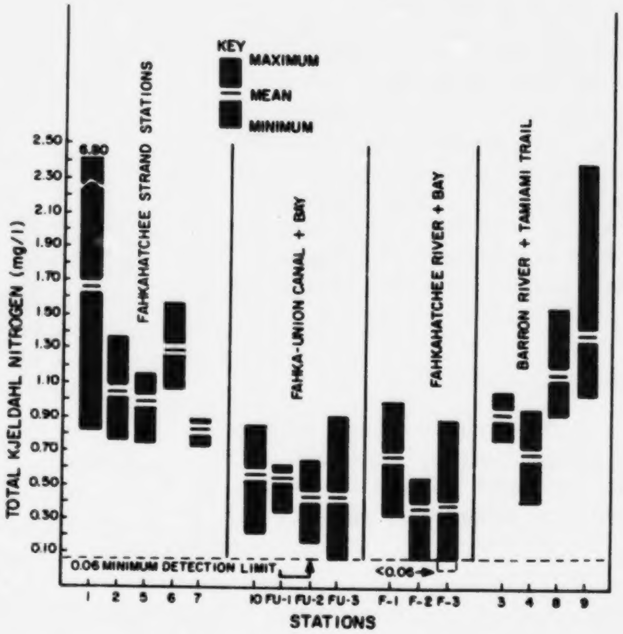

Figure X-10. The mean and range values for total Kjeldahl nitrogen.

The highest average total organic carbon (TOC) concentration (26 mg/l) was found at Stations 6 and 9. During April, the highest TOC concentration (36 mg/l) was found at the latter station. Also during this same month, the highest phosphorus concentration and next-to-the-highest Kjeldahl nitrogen concentration was found at Station 9. This occurred during a period of minimum water flow. Of the freshwater stations, the Fahkahatchee Strand stations had the highest average TOC concentrations (15 to 26 mg/l), the Barron River stations

Table X-6. The percentage of total Kjeldahl nitrogen that is total soluble Kjeldahl nitrogen.

Station	Percentage	Station	Percentage
1	81	9	82
2	84	10	95
3	87	F-1	85
4	90	F-2	100
5	90	F-3	79
6	79	FU-1	82
7	83	FU-2	81
8	88	FU-3	68

were next (13 to 17 mg/l), and Station 10 had the lowest of 12 mg/l. No apparent differences in TOC concentrations occurred between the bays. The high average TOC concentration of 17 mg/l at Station F-1 was caused by the direct drainage of a salt marsh. No insoluble form of total organic carbon was detected. The maximum, minimum, and mean concentrations for total organic carbon for each station are presented in Figure X-12.

Nutrient Transport

Originally, four of the 16 water quality stations were incorporated into a special study to determine surface

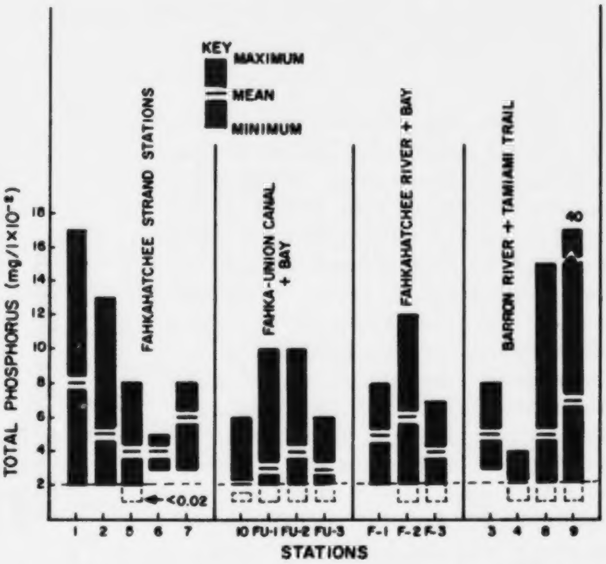

Figure X-11. The mean and range values for total phosphorus.

Table X-7. The percentage of total phosphorus that is total soluble phosphorus.

Station	Percentage	Station	Percentage
1	38	9	7
2	30	10	0
3	14	F-1	60
4	55	F-2	32
5	30	F-3	48
6	40	FU-1	13
7	17	FU-2	22
8	20	FU-3	60

water transport of nutrients from the freshwater areas to the estuaries. Of these four stations (10, 9, 8 and 4), two (Stations 8 and 9) were found to be subject to tidal influence. Consequently, these two stations were replaced with the three Janes Drive stations (Stations 5, 6 and 7). Stations 10 and 4 (Fahka Union Canal and Barron River respectively) were sampled weekly, and the stations on Janes Drive (Stations 5, 6 and 7) were sampled monthly. Each sample was analyzed for total organic carbon, total Kjeldahl nitrogen, and total phosphorus. The results of each analysis are reported as either the average kg/day of nutrients per week transported by the Fahka Union Canal and the Barron River or as the average kg/day per month transported across Janes Drive. Because nutrient concentrations were not linearly related to flow (Figure X-13), an average flow, based on flows during the week or month that the sample was taken, was calculated. Then, the

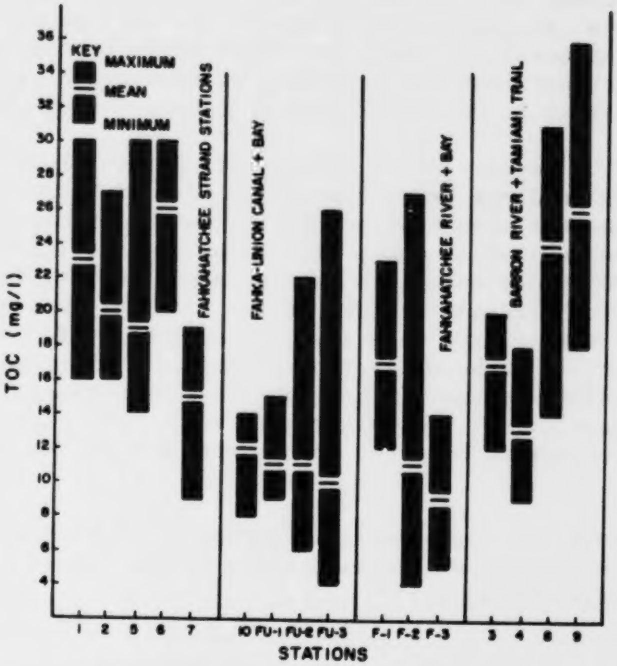

Figure X-12. The mean and range values for total organic carbon.

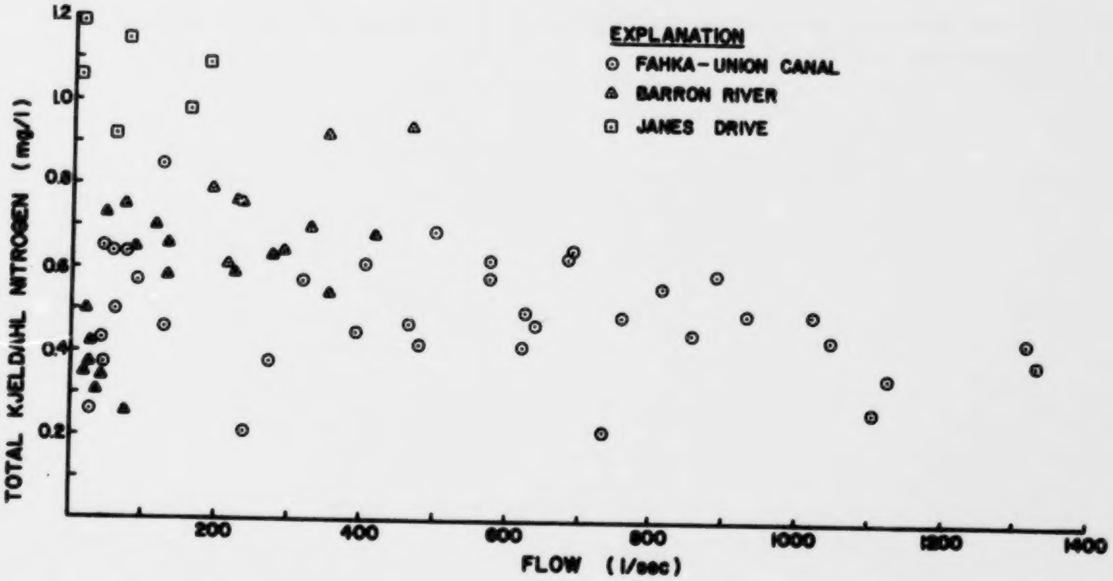

Figure X-13. Total Kjeldahl nitrogen versus flow.

average flow was multiplied by each nutrient concentration for the Fahka Union Canal and Barron River and by the average of each nutrient concentration of Stations 5, 6, and 7 for Janes Drive to give the average transport (kg/day) of each nutrient for each week or each month, as the case may be. This study started in March 1972 and continued through December 1972.

Because of an absence of surface flow, no nutrients were transported across Janes Drive from the middle of March to the middle of August. The greatest amount of nutrients was transported by the Fahka Union Canal during the week of June 20, with an average of 1,200 kg/day total Kjeldahl nitrogen, 290 kg/day total phosphorus, and 52,000 kg/day total organic carbon. This was the result of heavy rains received from Hurricane Agnes during the week. More nutrients were also transported by Fahka Union Canal for the year than by either of the other two systems (Fahkahatchee Strand or the Barron River). The average amount of nutrients (kg/day) transported by or across each freshwater area during 1972 is given in Table X-8. The average amount of nutrients (kg/day) transported by Fahka Union Canal and Barron River for each week and across Janes Drive for each month is presented in Figures X-14 through 16 and is given in Tables X-9 through 11.

Table X-8. The average transport (kg/day) of total Kjeldahl nitrogen, total phosphorus, and total organic carbon into the estuary from three freshwater areas during 1972.

Station	Nitrogen	Phosphorus	Carbon
Fahka Union Canal	260	20	7,600
Barron River	130	10	2,900
Janes Scenic Drive	58	2.2	1,100

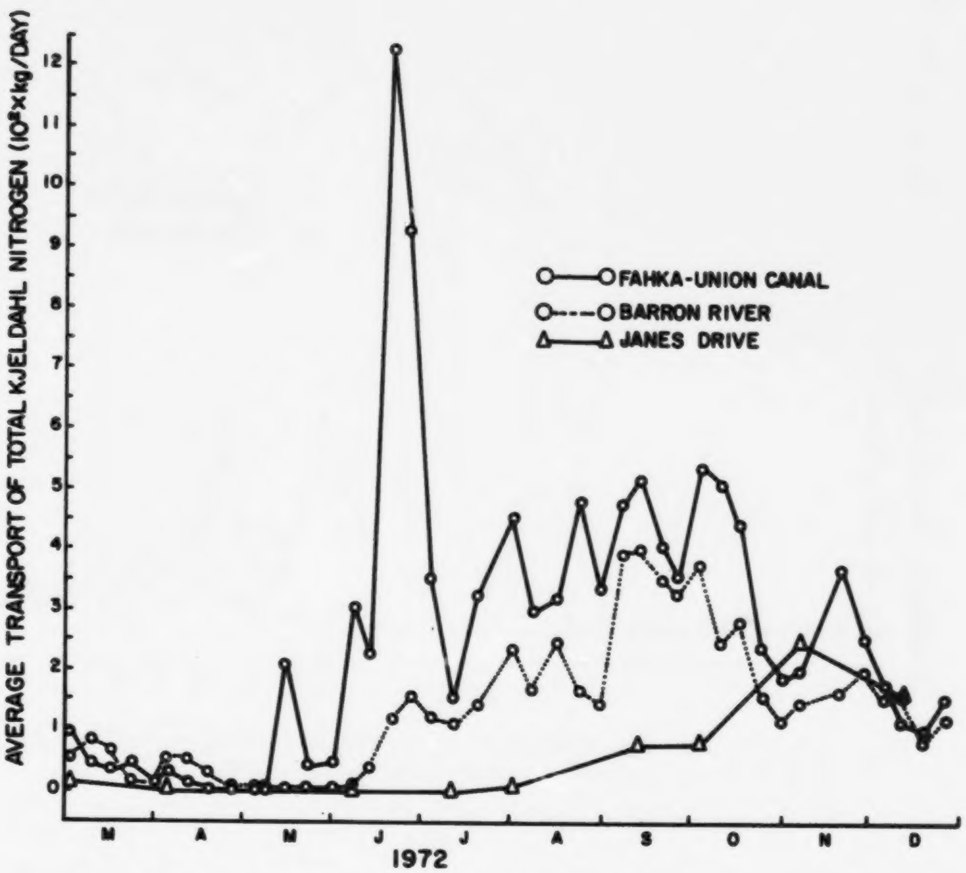

Figure X-14. Average transport of total Kjeldahl nitrogen (kg/day) from three freshwater areas into the estuary.

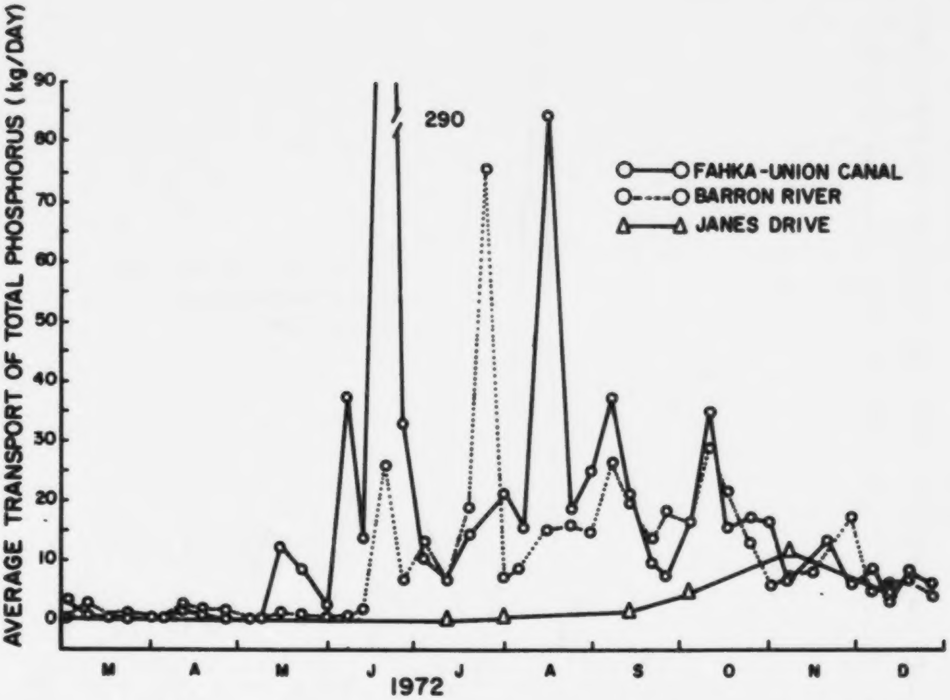

Figure X-15. Average transport of total phosphorus (kg/day) from three freshwater areas into the estuary.

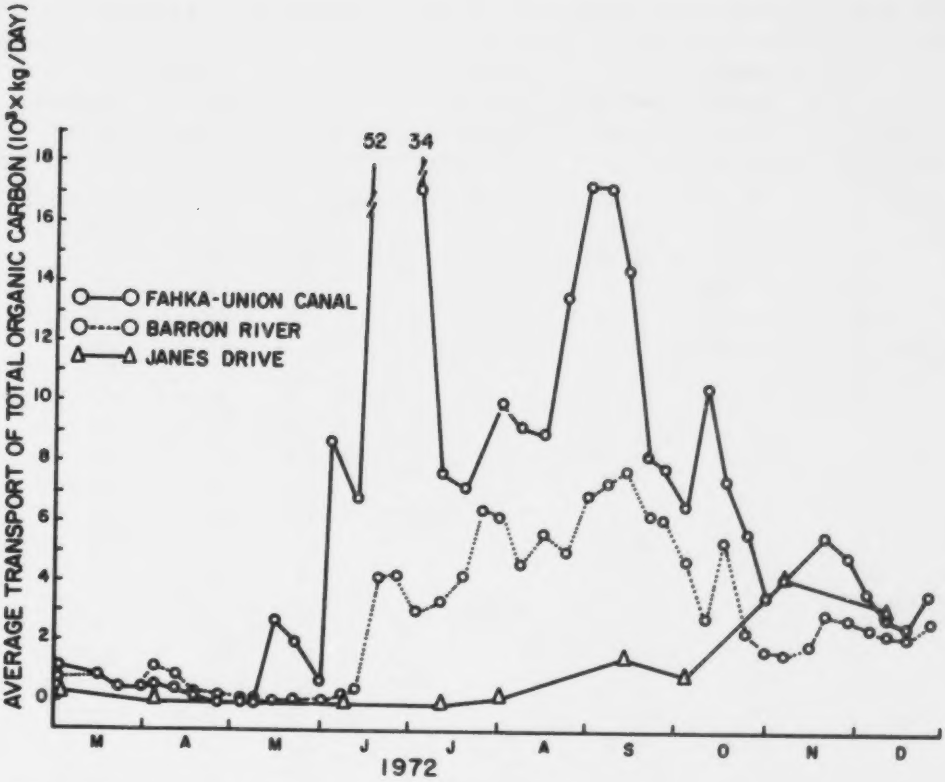

Figure X-16. Average transport of total organic carbon (kg/day) from three freshwater areas into the estuary.

Table X-9. The average transport of total phosphorus (kg/day).

Date	Fahka Union Canal	Barron River	Janes Scenic Drive	Date	Fahka Union Canal	Barron River	Janes Scenic Drive
Mar. 2	3.4	0.8	0.67	Aug. 1	22	7.0	0.32
9	0.93	2.8		7	15	8.3	
16	0.61	0.94		15	84	15	
23	0.73	1.4		23	18	16	
30	0.44	0.76		29	25	15	
Apr. 4	0.93	0.75	0.0	Sept. 6	37	26	
11	1.6	2.8		12	21	20	1.3
18	0.88	1.2		20	9.2	14	
26	0.0	1.7		25	7.1	18	
May 4	0.0	0.44	0.0	Oct. 3	17	16	4.2
8	0.15	0.56		10	35	29	
15	12	1.1		16	15	21	
22	8.2	0.94		24	17	13	
30	2.1	0.55		31	16	5.7	
June 7	37	0.58	0.0	Nov. 6	6.6	7.8	11
12	14	1.7		15	ND*	8.0	
20	290	26		20	13	ND*	
26	33	6.5		28	5.6	17	
July 3	10	13		Dec. 5	8.4	4.8	
11	7.0	6.4	0.0	11	3.3	6.0	4.1
19	14	18		18	8.0	6.5	
25	ND*	75		26	5.4	3.9	

* No data

Table X-10. The average transport of total Kjeldahl nitrogen (kg/day).

Date	Fahka Union Canal	Barron River	Janes Scenic Drive	Date	Fahka Union Canal	Barron River	Janes Scenic Drive
Mar. 2	98	52	12	Aug. 1	450	230	6.8
9	43	84		7	300	170	
16	31	66		15	320	250	
23	42	18		23	480	170	
30	19	13		29	330	150	
Apr. 4	30	58	0.0	Sept. 6	480	390	
11	14	54		12	520	400	77
18	2.5	30		20	410	350	
26	0.0	9.0		25	360	330	
May 4	0.0	9.4		Oct. 3	540	380	77
8	3.2	9.3	0.0	10	510	250	
15	210	6.6		16	440	280	
22	43	4.7		24	240	160	
30	45	5.7		31	190	120	
June 7	310	12	0.0	Nov. 6	200	150	250
12	230	37		15	ND*	ND*	
20	1,200	120		20	370	160	
26	950	160		28	260	200	
July 3	350	120		Dec. 5	180	150	
11	150	110	0.0	11	110	150	160
19	320	140		18	100	76	
25	ND*	ND*		26	150	120	

* No data

Table X-11. The average transport of total organic carbon (kg/day).

Date	Fahka Union Canal	Barron River	Janes Scenic Drive	Date	Fahka Union Canal	Barron River	Janes Scenic Drive
Mar. 2	1,100	800	170	Aug. 1	10,000	6,300	170
9	ND*	ND*		7	9,200	4,700	
16	860	760		15	9,000	5,700	
23	510	480		23	14,000	5,100	
30	480	460		29	17,000	6,900	
Apr. 4	600	1,200	0.0	Sept. 6	17,000	7,400	
11	430	940		12	14,000	7,800	1,600
18	220	360		20	8,300	6,300	
26	0.0	310		25	7,900	6,200	
May 4	0.0	160	0.0	Oct. 3	6,600	4,800	960
8	59	190		10	12,000	2,900	
15	2,800	140		16	7,500	5,500	
22	2,100	120		24	5,700	2,500	
30	780	120		31	3,600	1,900	
June 7	8,700	320	0.0	Nov. 6	4,300	1,800	4,300
12	6,800	480		15	ND*	2,100	
20	52,000	4,200		20	5,700	3,100	
26	34,000	4,300		28	5,000	2,900	
July 3	17,000	3,100		Dec. 5	3,800	2,600	
11	7,700	3,400	0.0	11	3,000	2,400	3,300
19	7,200	4,300		18	2,700	2,300	
25	ND*	6,500		26	3,800	2,900	

* No data

XI - METALS AND PESTICIDES

INTRODUCTION

This section documents the distribution and concentration of metals and pesticides found in the Barron River, Fahkahatchee Strand, and associated estuaries. At present, no significant use of pesticides or metals was found within the study area; however, the study area has been affected to some extent by extensive agriculture applications of these chemicals in immediate upland areas. The primary objective of this study was to determine if unnatural levels of pestecides and metals were present and to obtain background data for future studies.

METHODS

During December 1971, seven stations which were representative of the study area were established--two stations (Stations 4 and 7) in the undeveloped areas and five stations (Stations 1, 2, 3, 5, and 6) in the developed areas. These stations were sampled on a quarterly basis for 1 year starting January 24, 1972. Station locations are given in Table XI-1 and shown on Figure XI-1. Methods for collection and analysis, and a list of each pesticide and metal analyzed for are discussed below.

Table XI-1. Location of stations for pesticide and metal analyses.

Station	Location
1	GAC Canal beside Alligator Alley (S. R. 84) 16.3 km (10.1 miles) east of the west-end toll booth. A freshwater station.
2	Bridge on Alligator Alley (S. R. 86) 31.4 km (19.5 miles) east of the west-end toll booth. Off-shoot of the Borrow Canal draining southward into the Fahkahatchee Strand. A freshwater station.
3	Barron River Canal in front of Jane's Resturant on S. R. 29. A freshwater station.
4	The first wooden bridge (bridge E) 4.8 km (3 miles) on Janes Scenic Drive. A freshwater station on the outer edge of the Fahkahatchee Strand.
5	Bridge #71 on U. S. 41 (Tamiami Trail). An off-shoot of the Borrow Canal draining southward into a salt marsh. It has brackish water and subject to tidal influence.
6	Fahka Union Bay west of Black Marker #35, which is a shallow area away from the main channel.
7	Approximate middle of Fahkahatchee Bay.

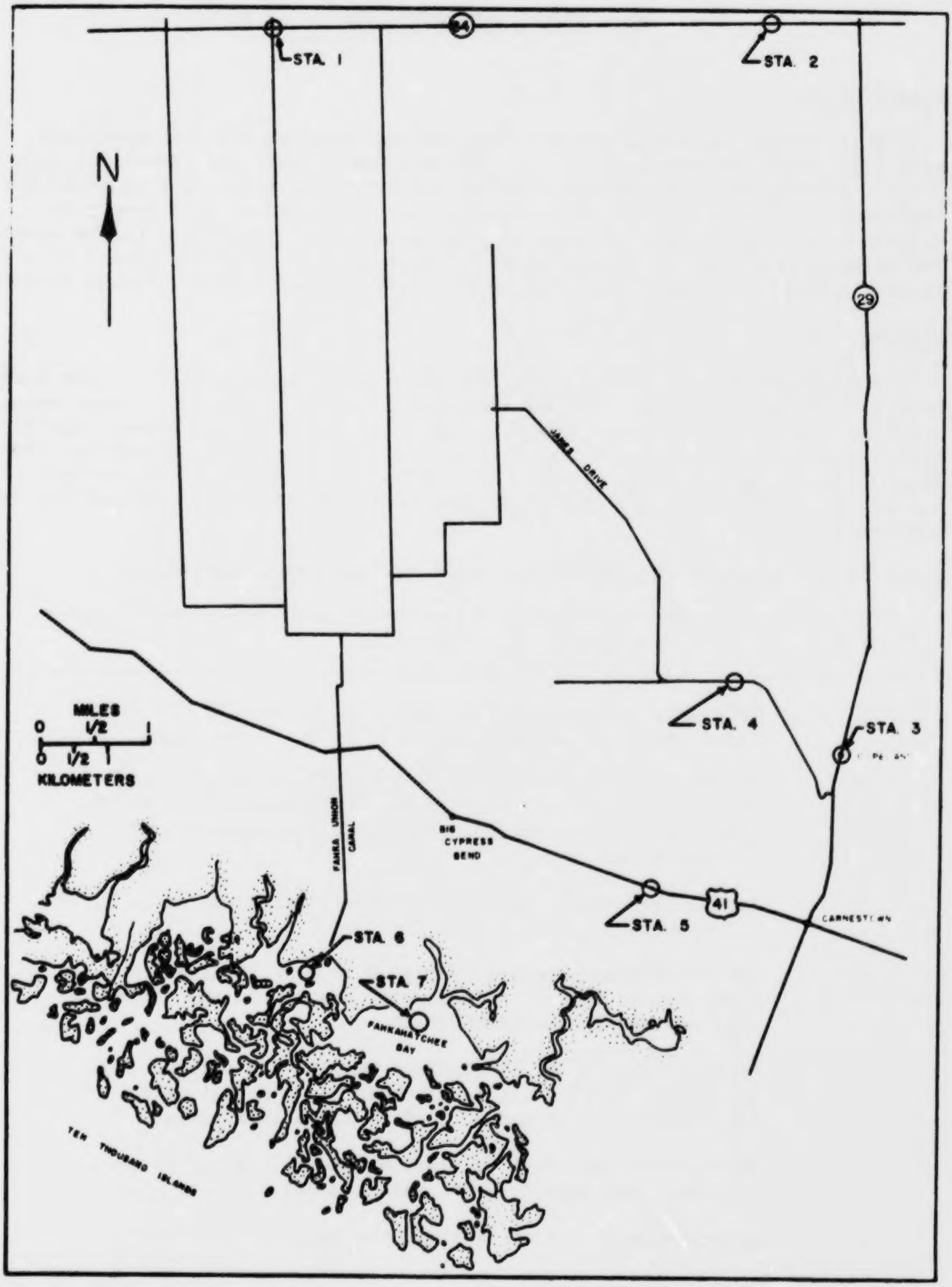
STA. 1
84
STA. 2
N
29
JAMES DRIVE
MILES
0 1/2 1
0 1/2 1
KILOMETERS
STA. 4
STA. 3
FAHKA UNION CANAL
BIG CYPRESS BEND
STA. 5
41
CARNESTOWN
STA. 6
STA. 7
FAKAHATCHEE BAY
TEN THOUSAND ISLANDS

Figure XI-1. Location of the pesticide and metal stations.

Metals

Water and sediment samples were collected at each station. Water samples were taken directly in clean, 1-quart, wide-mouth jars; and the sediment samples were taken by use of an Ekman dredge and then placed into the same type jar. Upon return to the Naples laboratory, the water samples were preserved with 5 ml HNO_3. No preservative was used for the sediment samples. The samples were then immediately shipped to the Southeast Environmental Research Laboratory (SERL) in Athens, Georgia, for analysis.* The EPA's atomic absorption method for total metals was used for each metal analysis. Both sediment and water samples were analyzed for arsenic, chromium, copper, lead, nickel, zinc, manganese, cadmium, and mercury. Only water samples were analyzed for iron.

Pesticides

Water, sediment, and fish samples were collected at each station. Water samples were taken directly into a pesticide-free, 1-quart, wide-mouth glass jar with aluminum foil-lined lids. Sediment samples were taken using an Ekman dredge and then placed in the same type jar. Fish samples were collected using a seine or "hook and line" and then immediately put on ice. Upon return to the Naples laboratory, the water and sediment samples were immediately shipped to the SERL in Athens, Georgia. The fish were kept on ice until they were counted, weighed, and measured; and then they were frozen and subsequently packed in dry ice and sent to the Athens laboratory. EPA's gas chromatographic method was used for each pesticide analysis. In addition to the quarterly samples, various other animal samples, which were dead when found, were collected and analyzed for the same pesticides as the fish.

The pesticide analysis for each type sample and the minimum detection limits are presented in Table XI-2.

RESULTS

Metals

Analytical results for both water and sediment samples are presented in Tables XI-3 and 4 respectively.

Arsenic was not detected in the water at any station; however, at most of the stations, some was detected in the sediment. At Stations 3 and 6, arsenic was detected 100 percent of the time; but at Stations 4, 5, and 7, none was detected. The highest concentration of 11.5 μg/g was found at Station 3 during April.

No cadmium was detected in the water at Stations 1 through 4, and it was found only during January at Station 5. However, it was found in almost all the samples from Stations 6 and 7, with the highest value of 50 μg/l being detected during January and April at Station 7. At the Stations where cadmium was detected, a decreasing trend was seen from January through November.

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* Analysis performed by Chemical Services Branch, Surveillance and Analysis Division, Region IV, Environmental Protection Agency, Athens, Georgia.

Table XI-2. Pesticide analyses and minimum detection limits.

Pesticide	Minimum detection limit in water (μg/l)	Minimum detection limit in sediment and biological samples (μg/kg)
Aldrin	0.005	0.25
Lindane	0.002	0.1
Chlordane	0.05	2.5
Chlorobenzilate	0.5	25
DDD	0.01	0.5
DDE	0.01	0.5
DDT	0.02	1.0
Dieldrin	0.01	0.5
Endrin	0.02	1.0
Heptalchlor Epoxide	0.01	0.5
Heptachlor	0.005	0.25
Methoxychlor	0.1	5.0
Toxaphene	0.25	15
Diazinon	0.2	10
Guthion	0.5	25
Methyl Parathion	0.2	1
Parathion	0.02	2
Malathion	0.04	4
Ethion	0.02	4
Trithion	0.1	2
Mirex	0.05	1
Dimethoate (cygon)	1	50
Lannate*	2	100
PCB's	0.05	5.0

* Analyzed for in sediment and water only.

Cadmium was detected in the sediment at every station except Station 7. The highest median value of 3.9 μg/g and the highest concentration of 6.0 μg/g were found at Station 2. There was also a decreasing trend through the year.

Chromium was detected in the water only at Station 5 during July at a concentration of 60 μg/l; however, it was detected in the sediment at every station during the year. The highest median values of 34.8 μg/g and 36.0 μg/g were found at Stations 2 and 6 respectively, but the highest concentration of 67 μg/g was found at Station 1 during January.

No copper was detected in the water at Station 1 through 4. However, it was detected at Station 6 and 7 throughout the year and at Station 5 during November. The highest concentration of 60 μg/l was found at Station 7 during November.

Copper was detected in the sediment at every station throughout the year. The highest concentration of 18.5 μg/g was found at Station 1 during July. The highest median values of 9.8 μg/g and 8.6 μg/g were found at Stations 1 and 3 respectively, and lowest median value of 2.8 μg/g was found at Station 7.

Table XI-3. Metal analysis for water samples in μg/l.

Station	Nickel				Zinc				Lead			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	< 50	< 100	< 50	< 20	< 10	30	< 50	50	250	<100	<100	< 100
2	< 50	< 100	< 50	< 20	< 10	40	< 50	< 20	< 50	<100	<100	< 100
3	< 50	< 100	< 50	-	< 10	< 30	< 50	-	< 50	<100	<100	-
4	< 50	< 100	< 50	-	< 10	50	70	-	< 50	<100	<100	-
5	< 50	280	50	50	< 10	100	< 50	30	< 50	200	<100	< 100
6	115	630	110	120	30	100	< 50	< 20	330	370	100	250
7	140	670	210	200	30	100	100	40	330	300	270	500

Station	Manganese				Cadmium				Mercury			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	<10	< 30	<50	60	<10	<25	<25	<20	-	<0.2	<0.5	<0.2
2	<10	50	<50	80	<10	<25	<25	<20	-	<0.2	<0.5	<0.2
3	<10	< 30	<50	-	<10	<25	<25	-	-	<0.2	<0.5	-
4	<10	< 30	<50	-	<10	<25	<25	-	-	<0.2	<0.5	-
5	130	200	70	50	30	<25	<25	<20	-	<0.2	<0.5	<0.2
6	40	90	<50	40	40	45	<25	20	-	<0.2	<0.5	<0.2
7	50	80	70	70	50	50	35	30	-	<0.2	<0.5	<0.2

Station	Copper				Chromium				Arsenic			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	< 10	< 30	< 50	< 20	< 50	< 50	< 50	< 40	-	< 20	-	< 29
2	< 10	< 30	< 50	< 20	< 50	< 50	< 50	< 40	-	< 20	-	< 29
3	< 10	< 30	< 50	-	< 50	< 50	60	-	-	< 20	-	-
4	< 10	< 30	< 50	-	< 50	< 50	< 50	-	-	< 20	-	-
5	< 10	< 30	< 50	< 20	< 50	< 50	< 50	< 40	-	< 20	-	< 29
6	30	36	< 50	< 20	< 50	< 50	< 50	< 40	-	< 20	-	< 29
7	30	43	50	60	< 50	< 50	< 50	< 40	-	< 20	-	< 29

Station	Iron			
	Jan.	Apr.	July	Nov.
1	-	< 300	140	1,150
2	-	800	300	620
3	-	380	460	-
4	-	< 300	100	-
5	-	5,600	570	170
6	-	460	220	330
7	-	540	270	380

NOTE: **< indicates results were below minimum detection limit, which changes periodically depending upon the condition of the atomic absorption unit.**

- indicates analysis was not conducted.

Table XI-4. Metal analysis for sediment samples in µg/g.*

Station	Nickel				Zinc				Lead			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	58	8.0	14.4	13.0	63	12.4	9.2	7.3	40	30.8	16.0	25.3
2	50	12.0	10.8	6.7	74	19.2	8.8	5.9	230	44.7	28.8	7.9
3	26	4.0	6.4	10.3	30	34.8	62.7	101	28	64.8	160	41.7
4	14	6.0	3.6	<1.5	11	16.6	10.0	<1.5	17	28.0	7.2	2.4
5	26	3.6	2.8	-	16	10.8	4.0	-	52	1,079	4.0	-
6	20	8.0	14.0	12.8	5	7.2	10.6	11.2	20	9.6	24.3	23.9
7	8	5.6	6.0	7.3	4	5.4	4.4	5.5	16	9.4	9.2	8.0

Station	Manganese				Cadmium				Mercury			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	152	16	15.6	27.7	3	1.2	0.8	2.0	0.47	<.04	<.10	<.04
2	56	46.5	13.2	18.9	5	6.0	2.8	0.8	.08	<.04	.20	<.04
3	34	20.4	46.7	44.0	2	0.8	0.8	1.6	.07	.10	.20	<.04
4	12	20.6	6.7	2.0	1	1.2	<0.8	<0.8	.07	<.04	.14	<.04
5	38	14.4	5.6	-	1	0.8	<0.8	-	<.04	.22	.19	-
6	20	20.2	36.0	39.9	2	0.8	1.2	0.8	.26	.04	1.42	<.04
7	8	15.6	15.6	17.0	<1	<0.8	<0.8	<0.8	.09	.06	.44	.08

Station	Copper				Chromium				Arsenic			
	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.	Jan.	Apr.	July	Nov.
1	10	5.6	18.5	5.3	67	15.2	12.4	24.9	<1.6	<2.0	2.6	2.8
2	6	6.0	5.2	2.0	47	25.6	34.4	32.0	8.4	<2.0	<2.0	<2.0
3	9	6.0	9.6	9.9	20	14.0	14.8	28.2	2.6	11.5	5.8	3.0
4	2	4.8	4.4	1.2	8	14.8	8.8	2.8	<1.4	<2.0	<2.0	<2.0
5	6	6.8	1.6	-	12	4.8	11.9	-	<1.3	<2.0	<2.0	-
6	3	3.2	5.0	4.6	20	27.2	52.7	44.3	6.4	3.4	3.5	4.8
7	3	2.7	2.6	2.9	8	17.6	14.4	20.5	<1.4	<2.0	<2.0	<2.0

* Analyzed and reported on a dry-weight basis except mercury which was reported on a wet-weight basis.

NOTE: < indicates results were below minimum detection limit, which changes periodically depending upon the condition of the atomic absorption unit.

- indicates analysis was not conducted.

Iron was consistently detected at Stations 2, 3, 5, 6, and 7 and in over 50 percent of the samples from Stations 1 and 4. No unusual concentrations were found at any station except at Station 5 where 5.60 mg/l was found during April. In the study area and surrounding areas, iron is used in many fertilizers and fungicides (ex. furbam for both domestic and commercial use). Also, in this area, iron concentrations of 900 µg/l were found in shallow wells; and higher concentrations were found in deeper wells (Finney and Miller, 1960).

In the water, 250 µg/l of lead was found at Station 1 during January, 200 µg/l was found at Station 5 during April; and lead was detected in all samples at Stations 6 and 7. The highest concentration of 500 μg/l was found at Station 7 during November. When lead was detected, it was from two to ten times higher than the USPHS Drinking Water Standards (0.05 mg/l).

Lead was detected in all sediment samples. The highest concentration of 1,079 μg/g was found at Station 5 during April. The two highest median values of 53.3 and 52.0 μg/g were found at Stations 3 and 5 respectively, and the two lowest median values of 21.1 and 9.3 μg/g were found at Stations 4 and 7 respectively. In the study area, lead is found in the pesticide (lead arsenate) and as lead tetraethyl in car exhaust and boat fuel.

Manganese was detected in the water 75 to 100 percent of the time at Stations 5 through 7 and 50 percent or less at the other stations. The highest concentration of 200 μg/l was found at Station 5 during April. Manganese was detected in the sediment at every station during the year. The highest concentration of 152 μg/g was detected at Station 1 during January. The highest median value of 45.3 μg/g was found at Station 2.

Mercury was not detected in the water at any time, but it was detected at least once during the year in the sediment at each station. The highest concentration of 1.42 μg/g was found at Station 6 during July.

Nickel was not detected in the water at Stations 1 through 4, but it was consistently detected at Stations 6 and 7 and 75 percent of the time at Station 5. The highest concentration of 670 μg/l was found at Station 7 during April.

Nickel was detected in the sediment at each station throughout the year except during November at Stations 4 and 5. The highest concentration of 58 μg/g was found at Station 1 during January. The highest median values of 13.7 and 13.4 μg/g were found at Stations 1 and 6 respectively, and the lowest median values of 4.8 and 3.6 μg/g were found at Stations 4 and 5 respectively.

The highest concentration of zinc of 100 μg/l was found at Stations 5, 6, and 7 during April and also at Station 7 during July. Zinc was not detected at Station 3. It was detected in all sediment samples except samples from Stations 4 and 5 during November. Station 3 had the highest sediment median value of 48.7 μg/g, which was three to ten time higher than the median values for the other stations. Station 7 had the lowest median value of 4.9 μg/g.

The median values for each metal at each station is given in Table XI-5. None of these metals were found to be used extensively within the study area; therefore, it is believed that the unnatural concentrations of most of these metals was caused by the drainage from upland agricultural industry. The unnatural concentration of lead is thought to be caused by the combination of car exhaust and drainage from upland agricultural industry.

Pesticides

Of the 24 pesticides analyzed for in the water and sediment samples, none were detected in the water at any time; and only six pesticides (DDT, DDD, DDE, Methoxychlor, PCB's, and Dieldrin) were detected in the sediment. Dieldrin was detected at Station 6 (13 μg/kg) during April and at Station 3 (2.3 μg/kg) during July. Methoxychlor was detected at Station 3 (2.1 μg/kg) during April.

Table XI-5. Median values for metal analysis of the sediment in μg/g.

Metal	Stations						
	1	2	3	4	5	6	7
Arsenic	2.3	<2.0	4.4	2.0	<2.0	4.1	<2.0
Cadmium	1.6	3.9	1.2	0.9	0.8	1.0	<0.8
Chromium	20.0	33.2	17.6	8.4	11.9	35.7	16.0
Copper	7.8	5.6	9.3	3.2	6.0	3.9	2.8
Lead	28.0	36.7	53.3	12.1	52.0	21.9	9.3
Manganese	21.8	32.7	45.3	9.3	14.4	28.1	15.6
Mercury	<.07	0.06	0.08	0.06	0.19	.15	.08
Nickel	13.7	11.4	8.4	4.8	3.6	13.4	6.6
Zinc	10.8	14.0	48.7	10.5	10.8	8.9	4.9

The concentration of DDT, DDD, DDE, and PCB's for each sediment sample is given in Table XI-6. The highest concentration of DDT, DDD, and DDE was 160, 160, and 96 μg/kg respectively; and they were found at Station 3 during April. The highest concentration of PCB's (130 μg/kg) was found at Station 2 during January. Both Stations 2 and 3 receive runoff from farmland in the Immokalee area where pesticides are used extensively.

Table XI-6. Results (μg/kg) of four pesticides detected in the sediment samples.*

Station	DDT				Station	DDD			
	Jan.	Apr.	July	Nov.		Jan.	Apr.	July	Nov.
1	ND**	3.2	ND	2.2	1	0.48	3.2	ND	0.88
2	ND	2.9	ND	ND	2	ND	2.9	1.0	1.4
3	2.7	160	ND	ND	3	13	160	ND	2.6
4	0.78	0.22	ND	ND	4	0.68	0.22	ND	ND
5	ND	0.69	ND	ND	5	1.8	0.69	ND	0.44
6	ND	0.58	ND	ND	6	0.61	0.58	ND	1.7
7	ND	0.22	ND	ND	7	ND	0.22	ND	ND

Station	DDE				Station	PCB			
	Jan.	Apr.	July	Nov.		Jan.	Apr.	July	Nov.
1	0.14	2.3	ND	0.40	1	ND	20	ND	ND
2	ND	2.4	0.73	1.1	2	130	5.7	ND	ND
3	4.2	96	ND	1.1	3	ND	5.2	ND	11
4	0.39	0.09	ND	ND	4	8	1.5	ND	ND
5	1.1	0.29	ND	0.37	5	ND	4.1	ND	4.2
6	0.23	0.28	ND	0.89	6	ND	ND	ND	ND
7	0.09	0.21	ND	ND	7	ND	2.6	ND	ND

* Sediment was calculated on a dry weight basis.

** ND - None detected.

In the biological samples, only six pesticides (DDT, DDE, DDD, PCB's, Dieldrin, and Mirex) of the 23 analyzed for were detected. Of these six, only four pesticides (DDT, DDE, DDD, and PCB's) were detected with significant frequency. Dieldrin was found in two fish during July and three fish during November. Mirex was observed once in a bobcat found dead on U.S. 41 near Ochopee, Florida. When a pesticide was detected, it was usually less than 50 µg/kg. The pesticide DDE was found in the highest concentrations of 320 µg/kg and 380 µg/kg; these concentrations were found in a Florida gar and a Bonito fish respectively. The concentration for each pesticide detected in each biological sample is presented in Tables XI-7 through 11. The scientific name for each fish taken for pesticide analysis can be found in Appendix MM.

The consistent absence of detectable pesticides in the water and the low concentrations found in the sediment and most of the biological samples suggest a lack of significant pesticide contamination at the present time. However, studies have shown that residue levels of chlorinated hydrocarbon pesticides in the water can build up in fish and other aquatic organisms to toxic concentrations for animals which feed upon those organisms (Cope, 1966; Butler, 1966; Keith, 1966). None of these pesticides were found to be used extensively within the study area; therefore, it is believed that most of the pesticides detected entered the study area from drainage of the upland agriculture industry, mainly by way of the Barron River.

Table XI-7. Pesticide analyses on biological samples for January.[a]

Station No.	Type of Sample	Size Range Total Length (mm)	DDE µg/kg	DDD µg/kg	DDT µg/kg	PCB's µg/kg
1	Largemouth bass	84	11.	2.8	7.0	35.
1	Brook silversides	32-82	6.8	0.7	2.3	12.
1	Spotted sunfish	122-134	4.2	1.1	2.3	12.
2	Florida gar	362	8.6	52.	25.	38.
2	Golden shiner	162	0.6	0.3	ND[b]	8.6
2	Redear sunfish	179	2.3	4.8	2.3	22.
3	Brook silversides	40-69	9.5	5.7	1.7	22.
3	Gambusia	19-40	26.	15.	9.1	42.
3	Florida gar	486	200.	94.	40.	110.
4	Flagfish	22-36	8.1	6.8	4.6	24.
4	Gambusia	22-46	18.	11.	10.	31.
4	Marsh killifish	83	23.	14.	11.	52.
5	Gambusia	17-44	16.	12.	6.5	28.
5	Florida gar	471	24.	20.	4.0	34.
5	Largemouth bass	197	9.2	11.	5.4	104.
6	Sheepshead	256	8.0	7.2	2.0	37.
6	Mangrove snapper	215	5.8	3.2	1.6	47.
6	Eastern oysters	-	0.7	1.0	0.76	22.
7	Sheepshead	380	12.	3.1	2.8	47.
7	Mangrove snapper	240	7.8	3.8	2.0	35.
7	Eastern oysters	-	1.7	1.8	1.0	16.
8[c]	Snook A	228	42.	51.	11.	85.
8	Snook B	156	40.	56.	12.	120.

[a] Based on whole fish analyses, calculated on a wet weight basis.

[b] ND - None detected.

[c] Station 8 was a station on Henderson Creek.

Table XI-8. Pesticide analyses on biological samples for April.[a]

Station No.	Type of Sample	Size Range Total Length (mm)	DDE µg/kg	DDD µg/kg	DDT µg/kg	PCB's µg/kg
1	Bowfin	561	8.7	9.1	6.3	ND[b]
1	Florida gar	662	320.	59.	4.5	110.
1	Yellow bullhead	313	3.2	3.9	2.3	ND
2	Bluegill	101-236	14.	7.8	17.	26.
2	Warmouth	116	3.4	ND	ND	ND
2	Spotted sunfish	86-201	7.4	3.8	6.8	23.
3	Bluegill	122-135	6.1	8.8	8.6	16.
3	Redear	98-129	6.7	3.4	4.0	ND
3	Gambusia	18-34	34.	48.	7.2	38.
4	Spotted sunfish	112-120	8.9	8.0	5.7	13.
4	Striped mullet	378	7.4	13.	5.5	76.
4	Gambusia	19-38	36.	13.	5.7	11.
5	Sailfin molly	28-56	14.	19.	13.	14.
5	Striped mullet	87	2.2	1.0	ND	ND
5	Redfin needlefish	316-318	24.	22.	16.	ND
6	Sheepshead	387	13.	9.3	3.8	ND
6	Gafftopsail catfish	428	12.	12.	7.6	ND
6	Eastern oyster	-	18.	1.6	7.4	ND
7	Sheepshead	300	8.	1.2	6.3	ND
7	Crevalle jack	288	32.	4.8	7.2	76.
7	Eastern oyster	-	12.	1.3	ND	20.

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[a] Whole fish analysis calculated on a wet weight basis.

[b] ND - None detected.

Table XI-9. Pesticide analyses on biological samples for July.[a]

Station No.	Type of Sample	Size Range Total Length (mm)	DDE µg/kg	DDD µg/kg	DDT µg/kg	Dieldrin µg/kg	PCB's µg/kg
1	Bluegill	189	55.	30.	10.	0.9	25.
1	Spotted sunfish	76-132	2.8	ND[b]	ND	ND	ND
1	Brook silverside	26-55	1.4	1.3	2.0	ND	16.
2	Redear sunfish	152	2.9	2.4	ND	ND	17.
2	Bluegill	139-168	8.1	3.9	4.9	ND	18.
2	Largemouth bass	331	73.	49.	30.	ND	80.
3	Florida gar	464	300.	85.	53.	ND	ND
3	Largemouth bass	62-99	3.7	ND	ND	ND	ND
3	Bluegill	175	4.9	3.7	4.4	ND	ND
4	Striped mojarra	242	19.	17.	4.0	ND	ND
4	Redfin needlefish	196-353	7.3	4.4	2.6	ND	36.
4	Tidewater silverside	22-61	12.	7.2	2.7	ND	21.
5	Snook	371	13.	5.4	ND	ND	ND
5	Redfin needlefish	261-340	1.4	ND	ND	ND	ND
5	Eastern oyster	-	0.76	ND	ND	ND	ND
5	Blue crab	156-184 (carapace width)	2.2	4.1	2.3	ND	ND
6	Spadefish	163-190	2.8	1.5	ND	ND	ND
6	Fantail mullet	195	2.6	2.9	ND	ND	ND
6	Eastern oyster	-	1.1	ND	ND	ND	ND
6	Blue crab	138-175 (carapace width)	2.1	ND	ND	ND	ND
7	Alligator - A.[c]	1,520	16.	ND	6.8	2.3	3.9
7	B.[d]		6.4	ND	ND	ND	ND

[a] Samples based on wet weight basis

[b] ND - None detected

[c] A. - Subcutaneous fat and muscle tissue from tail

[d] B. - Subcutaneous fat from abdominal region

Table XI-10. Pesticide analyses on biological samples for November.[a]

Station No.	Type of Sample	Size Range Total Length (mm)	DDE µg/kg	DDD µg/kg	DDT µg/kg	Dieldrin µg/kg	PCB's µg/kg
1	Bluegill	75-140	ND[b]	ND	ND	ND	ND
1	Spotted sunfish	85-95	1.6	ND	3.2	ND	ND
2	Redear sunfish	134-159	12.0	8.5	29.0	ND	ND
2	Bluegill	132-165	2.3	1.5	8.3	ND	ND
2	Spotted sunfish	123-138	1.6	1.6	3.6	ND	ND
3	Spotted sunfish	84-115	9.0	3.0	3.8	ND	ND
3	Redear sunfish	101-107	2.6	0.83	2.3	ND	ND
3	Bluegill	105-113	0.75	ND	ND	ND	ND
4	Gambusia	16-42	1.8	ND	ND	ND	ND
4	Yellow bullhead	36-48	ND	ND	ND	ND	ND
4	Bluegill	143	12.	3.3	6.6	ND	22.
5	Flagfish	17-33	4.1	3.7	2.5	ND	20.
5	Sailfin molly	20-52	11.	10.	14.	ND	ND
5	Florida gar	505	41.	16.	4.4	ND	ND
6	Common jack	327	24.	4.0	3.7	ND	ND
6	Sheepshead	215	2.1	1.9	2.7	ND	ND
6	Mangrove snapper	209-280	14	6.5	5.1	3.2	ND
6	Oysters	-	1.3	ND	ND	ND	ND
7	Crevalle jack	446	23.	11.	5.2	ND	ND
7	Mangrove snapper	289	6.6	ND	ND	2.2	ND
7	Oysters	-	0.9	ND	ND	ND	ND
7	Marine catfish	-	110.	9.1	1.9	1.6	ND

[a] Whole fish analysis, calculated on a wet weight basis.
[b] ND - None detected.

Table XI-11. Pesticide analyses on special biological samples.[a]

Station	Date of Sample	Type of Sample	DDE µg/kg	DDD µg/kg	DDT µg/kg	Mirex µg/kg	Dieldrin µg/kg	PCB's µg/kg
U.S. 41 (Ochopee, Fla.)	4/26/72	Bobcat	106.	4.3	9.8	4.0	11.	43.
		a. sub-epithelial fat						
		b. mesenteric fat	52.	ND	ND	23.	77.	230.
		c. liver	39.	12.	23.	1.5	9.3	19.
Shell Island Rd. Naples, Fla.	8/08/72	Armadillo (1150 g.)						
		a. liver	5.4	ND	1.1	ND	ND	ND
		b. fat tissue (subcutaneous)	ND	ND	ND	ND	ND	ND
		c. muscle (thigh)	ND	ND	ND	ND	ND	ND
Gulf of Mexico, 1.6 km off Marco Island, Fla.	11/16/72	Bonito fish (765 T.L. mm)	380.	54.	170.	ND	ND	300.

[a] Calculated on a wet weight basis
[b] ND - None detected

XII - PLANT COMMUNITY BIOMASS AND METABOLISM

MARINE GRASSES AND ALGAE

Introduction

The role of benthic marine plant communities in estuarine productivity requires little substantiation (Odum, 1968; Phillips, 1960; and Thorhaug and Stearns, 1972). These plants, apart from providing shelter and food for invertebrates and juvenile fishes, initiate biotic cycling of inorganic carbon. To date little information has been gathered on the rate at which these plants synthesize and use organic carbon. Hence, to properly judge an estuary's productivity would first require experimental work to determine net and gross primary productivity of these estuarine plant communities.

This section reports the experimental work conducted in Fahka Union and Fahkahatchee Bays in the Ten Thousand Island, Florida, for the purposes of determining the annual net and gross primary productivity of the benthic plant communities. Also, included is an assessment of various environmental factors effecting primary production.

To determine annual net primary productivity of the bay systems, the biomass accumulation approach was adopted. This method relies on biomass harvesting techniques the merits of which are discussed by Westlake (1971). Sampling was conducted in January, March, July, September, and November 1972 to determine changes in standing crop biomass. In determining gross primary productivity, specially designed benthic respirometers (Lucas and Thomas, 1970) were employed to measure dissolved oxygen exchange rates for the benthic communities during the spring and fall seasons 1972.

Methods

Survey of standing crop biomass in January first involved the development of a general map showing the distribution of plant densities in the two bays. This was accomplished during the bottom characterization study (Chapter VIII). At each of the established grid intersections, a bottom grab, obtained with a Petersen dredge, was sieved for its content of benthic vegetation. A No. 18 U. S. Standard sieve effectively separated vegetation from sediment. Vegetation, if present, was reported on a qualitative basis as trace, medium, or heavy amounts. This classification scheme was used to construct a map showing the distribution of plant densities in the bays. Soon after the qualitative categories were quantified in the following manner.

Bay areas designated as supporting trace, medium, or heavy amounts of vegetation were sampled with a screened scoop dèvice which effectively harvested plants within a 0.28 m^2 plot. The plant samples included roots and rhizomes which extended to a sediment depth of approximately 6 to 7 cm. Plant material was then separated from remaining sediment with a No. 18 U. S. Standard sieve, stored on ice, and returned to the laboratory at Rookery Bay for processing. Additional samples of vegetation were obtained, preserved, and later forwarded for identification to the Biological Services Branch, Surveillance and Analysis Division at the Southeast Environmental Research Laboratory in Athens, Georgia.

Processing of samples entailed first a sorting of the plant material by vegetative types - marine grasses, red marine algae, and green filamentous algae. Subsequently, all material was oven dried for three to four days at 103°C., cooled to room temperature and weighted. Average concentrations (gm dry wt./m^2) were calculated for each of the identified density categories.

The sampling scheme heretofore described was altered for the remaining surveys (March, July, September, and November). An Ekman dredge modified with a two meter shaft and special release mechanism was used for sampling. Two bottom grabs were obtained and composited at each of the grid intersections sampled. The composite sample represented two 15.2 X 15.2 cm bottom plots. As before, sediment penetration was restricted to 6 - 7 cm. Processing of the samples remained the same as in the January survey.

Vegetational concentrations were plotted at each of the respective grid intersections and appropriate isopleths drawn for the July and September surveys. The March and November survey results were not treated in this manner because they served as only spot checks on changes in standing crop biomass and limited to a fewer number of sampling sites. The isopleths indicate an average, weighted for bottom area and concentration, for each of the three substrate and vegetative types of Fahkahatchee and Fahka Union Bays.

Benthic gross primary production rates were determined for mud-sand and sand-mud bottoms in Fahka Union and Fahkahatchee Bays. Mud-sand bottoms were characterized by a soft substrate mainly composed of mud with fine sand as a secondary feature. The sand-mud substrate, of course, was the reverse in compositional features, but still soft in texture. The productivity studies were conducted during the spring of 1972 (February 15 to 19 and March 7 to 26) and during the fall of 1972 (October 26 to November 5). Study sites are indicated in Figure XII-1.

Production rates were determined using a black and a clear plexiglass chamber to measure the exchange rates of dissolved oxygen (DO) between bay water and the benthic community. Community in the sense used in the present study includes the biotic and abiotic elements, such as chemical oxygen demand, associated with the bottoms. Both chambers were identical in construction (Figure XII-2).

The chambers were constructed to maximize the ratio of bottom area to water volume in order to permit rapid detection of dissolved oxygen changes. Also, the construction elevated the circulation system sufficient distance from the bottom to minimize resuspension of fine bottom particles during the operation. Each chamber when sitting on a horizontal plane was slightly bias by design to allow gases to collect at one corner and escape via a check valve. The plexiglass portions of the chamber were bolted to a stainless steel flange and cutting edge which effectively seals the test water within the chambers when they are lowered onto any soft bottom sediment. Each chamber, in position, covered 0.186 m^2 of bottom and contained 14.5 liters of bay water. The entrapped water was circulated through the chamber and a clear plexiglass manifold by a 12 volt DC submersible pump mounted externally to the chamber. No seal monitoring system was used during the operation of the chamber when in place. Past experience in using the system in other studies indicated that the substrate types encountered in the present study would permit an effective chamber to sediment seal. Changes in dissolved

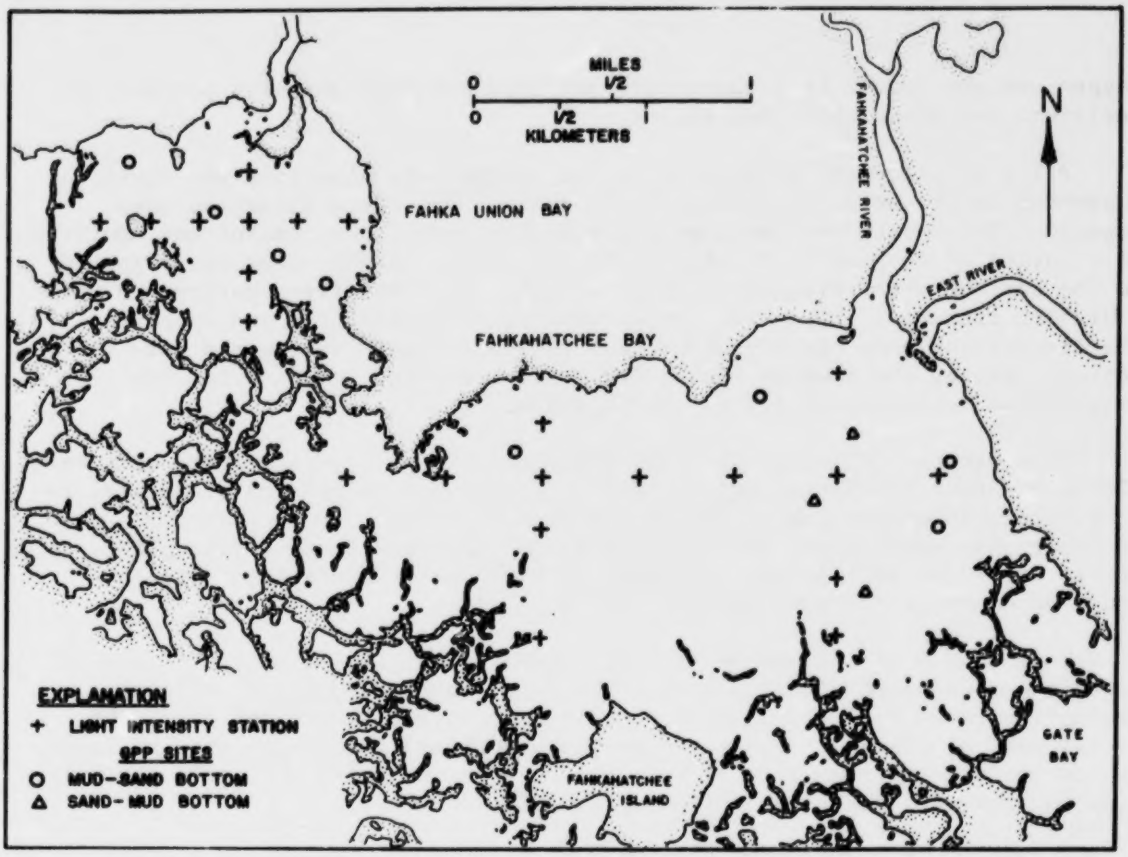
MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
FAHKAHATCHEE ISLAND
GATE BAY
EXPLANATION
+ LIGHT INTENSITY STATION
GPP SITES
O MUD-SAND BOTTOM
△ SAND-MUD BOTTOM

Figure XII-1. Locations of Stations Used in the Benthic Plant Gross Primary Productivity Studies and in the Surveys of Light Extinction in Fahka Union and Fahkahatchee Bays, 1972

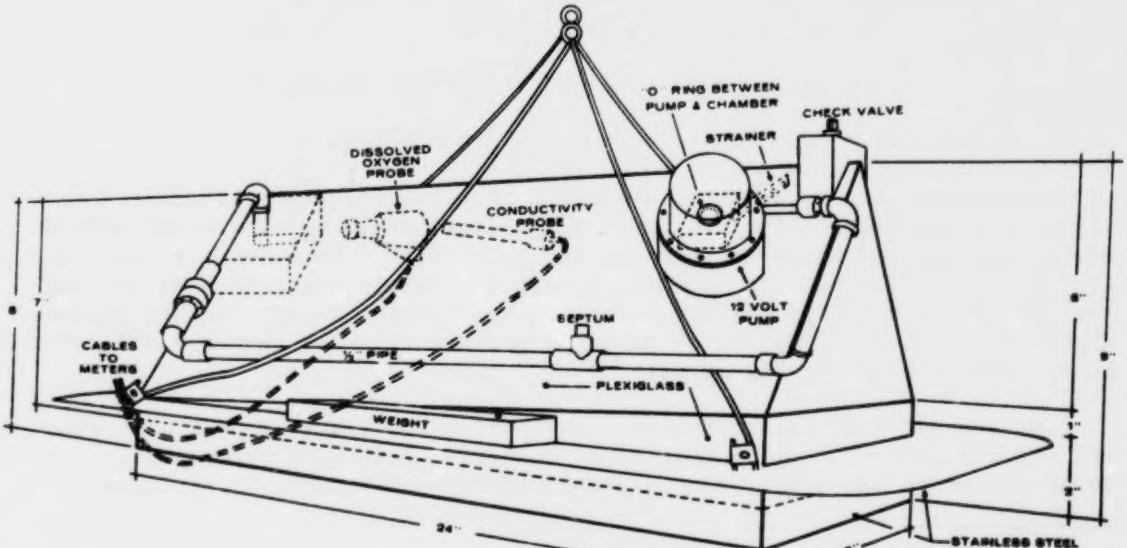
DISSOLVED OXYGEN PROBE
CONDUCTIVITY PROBE
"O" RING BETWEEN PUMP & CHAMBER
CHECK VALVE
STRAINER
12 VOLT PUMP
SEPTUM
1/2" PIPE
CABLES TO METERS
PLEXIGLASS
WEIGHT
8"
7"
6"
9"
1"
2"
24"
12"
STAINLESS STEEL SEALING FLANGE

Figure XII-2. Benthic Respirometer.

oxygen content of the test water were measured and recorded with portable DO analyzers and strip chart recorders.

Prior to placement of chamber on the bottom, the apparatus was first suspended in the water just beneath the surface and the circulation pump engaged. The system was operated a few minutes until the chamber and manifold were purged of trapped air bubbles. At this time, the DO meter was adjusted to the surface water dissolved oxygen content which was first determined with a Winkler titration. Once the system was correctly adjusted and operating, the circulation pump was disengaged and the unit carefully lowered onto the bottom. There, the chamber rested for several minutes to allow for any resuspended bottom particles to settle again.

Resuspension of bottom material while placing and operating the unit was always a threat to the success of test. Extensive resuspension would lead to an accelerated oxygen demand (Lucas and Thomas, 1970). To account for possible resuspension the unit's circulation was first stopped just prior to its retrieval so that water trapped in the clear circulation manifold could be examined for suspended or settled solids.

Test runs with the opaque (black) chamber provided estimates of the benthic community respiration rate. The clear chambers yielded net oxygen production rates for its enclosed benthic vegetation. In either case, the actual rate of change of DO with time was determined from regression analyses. To convert oxygen production or respiration rates to rates of carbon assimilation on an aerial basis the following calculation was used:

$$\beta \cdot K \cdot \frac{0.06V}{A} = \text{gm C/m}^2\text{/hr}$$

Where:

β = Regression Coefficient (mg O_2/1/min)

V = Volume of Chamber (14.5 1)

A = Bottom Area Confined to Chamber (0.186 m^2)

K = Mole Fraction of C_{12} and O_2 (0.375)

To establish a response relationship of gross primary productivity to light, visible light illumination at the chamber depth was monitored with a marine photometer[a] equipped with sea and deck cells. In advance of the study, the cells were checked for linear response to visible light intensities and the photometer readings calibrated to express radiant energy (within visible light range of 400 - 700 nm) as langleys per minute. The response and calibration curve is shown in Figure XII-3.

Additional work was performed to establish the fraction of total solar radiation represented by visible light spectra. For these experiments, total solar radiation was measured by a pyrheliometer under various conditions of cloud cover and sun elevation during the month of August 1972. Simultaneously, a spectral radiometer was deployed to measure visible light radiation. The faction of photosynthetically available energy included in the total daylight radiation received at Rookery Bay was 48.47 percent (Figure XII-4). This value is considered as a yearly constant for South Florida.

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[a] The instrument was constructed by personnel of the project to meet special application.

Fahka Union and Fahkahatchee Bays are relatively shallow estuaries. The interaction of wind velocity and tidal changes in depth were major factors effecting turbidity, hence, effecting light extinction. To arrive at a model describing the relationship of light extinction to wind and depth, surveys were conducted during 1972 and 1973 to measure light extinction in both bays.

Diminution of light intensity through the water column was determined in both bays at selected locations (Figure XII-1) and on various dates. The marine photometer used in the productivity tests was used for the surveys. Using the light intensity data coupled with measurements of depth, the following equation provided a measure of light extinction coefficients (K).

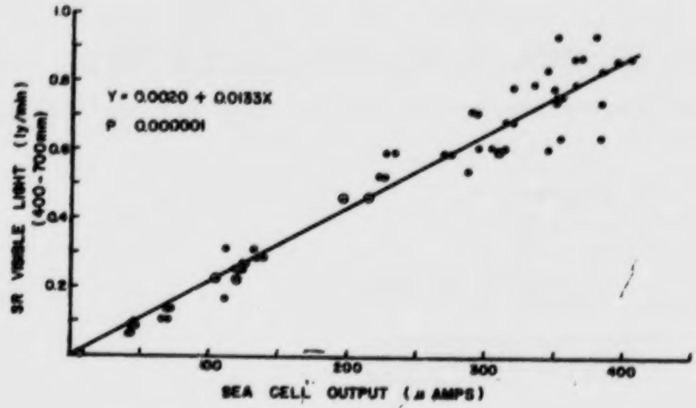


Figure XII-3. Response and Calibration Curve of the Marine Photometer.

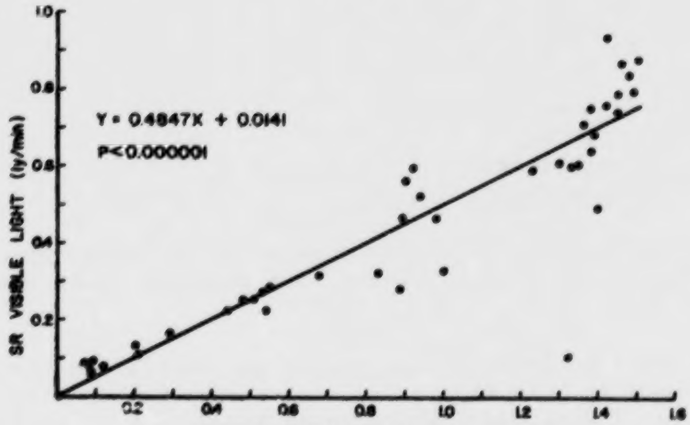


Figure XII-4. Total Solar Radiation Represented by Visible Light.

$$K = \frac{\ln \frac{I_z}{I_o}}{Z}$$

Where: I_z = Light Intensity at Z (μ amps)

I_o = Light Intensity at Surface (μ amps)

Z = Depth (cm) of Water Column

Scheduling of surveys was random from the standpoint of considering time of day, tides, and winds; hence, light extinction was measured under a wide range of conditions.

RESULTS

Benthic Vegetation and Standing Crop Biomass

Qualitative samples of the two bays yielded the following list of plant species:

- Marine grasses
    - Tracheophyta
        - Potamogetonacea
            - *Diplanthera wrightii*
    - Hydrocharitaceae
        - *Thalassia testudinum*
        - *Halophila engelmannii*

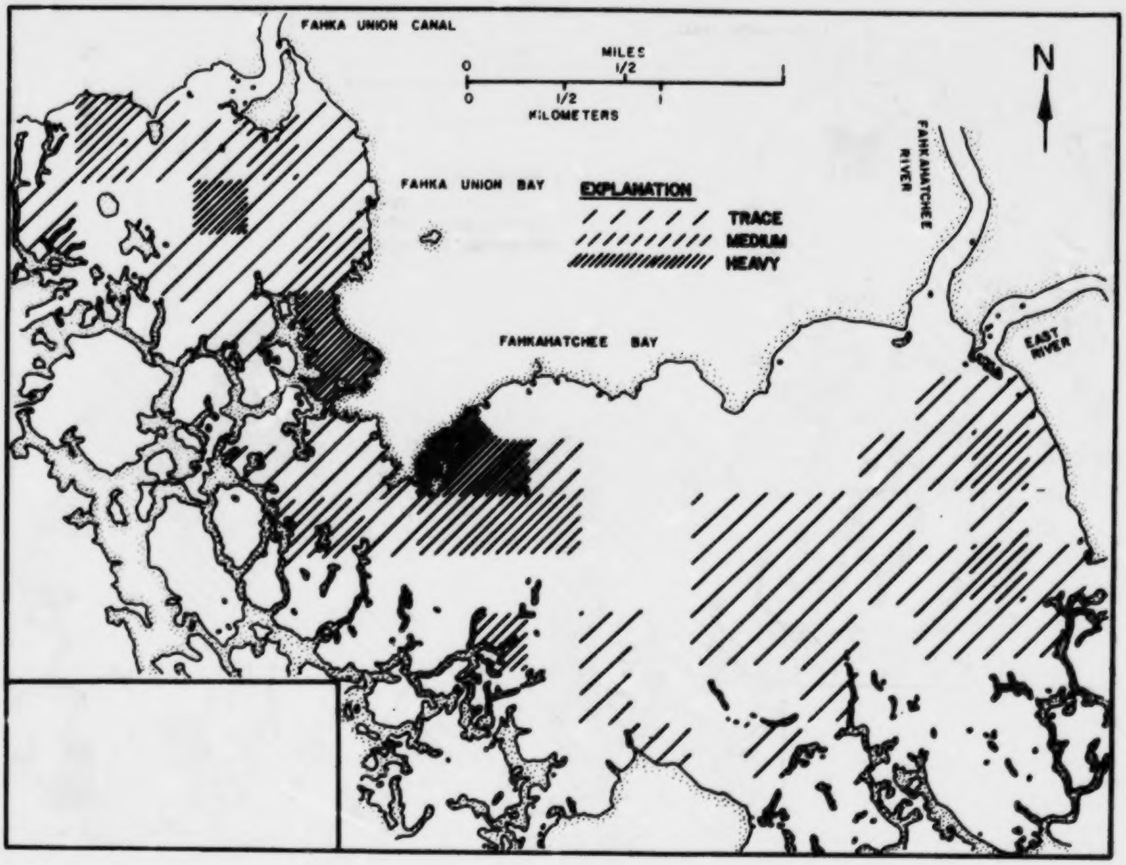
- Red macroalgae
    - Rhodophyta
        - Ceramiaceae
            - *Gracilaria verrucosa*
            - *Gracilaria sjoestedii*
            - *Gracilaria foliifera*
            - *Dasya harveyi*

- Green filamentous algae
    - Chlocophyta
        - Cladophoraceae
            - *Rhizoclonium hookeri*

Taxonomically, vascular plants designated as marine grasses are not members of the family Graminae. However, for purposes of this study they were referred to as such.

In January, green filamentous algae maintained the greatest standing crop biomass in both bays. Definitive concentration (gm dry wt/m^2) for the categories of densities indicated in Figure XII-5 are following: Trace - 0.6, medium - 8.9, and heavy - 46.9.

Comparative to the green filamentous algae, the standing crop of grasses and red macro-algae biomass were sparse during January. As before, the distribution and abundance of these two plant groups were broken down into categories of trace, medium, and heavy densities (Figures XII-6 and 7). Respectively, definitive concentrations were 0.6, 1.6, and 8.2 for the red macro-algae, 0.3 and 1.6 gm dry wt./m^2 for the grasses. Estimates of total standing crop biomass in January for the three plant types follows: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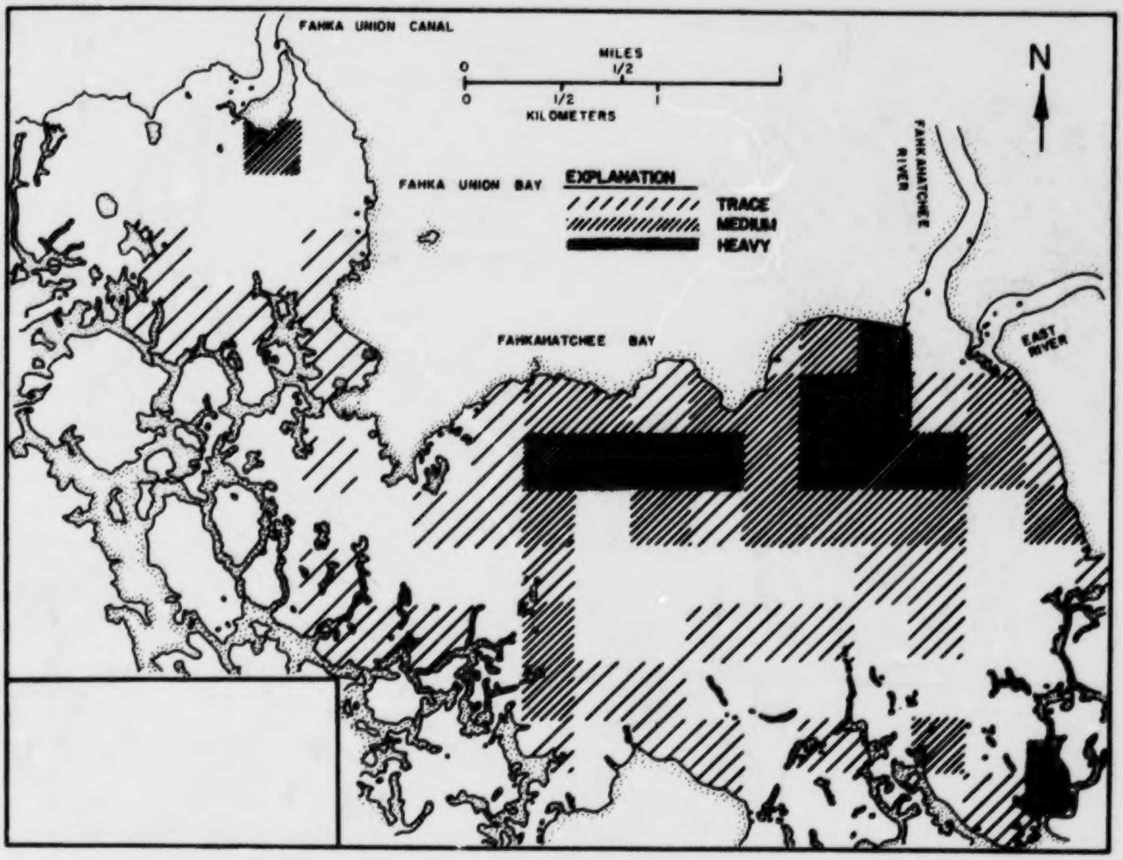
HEAVY
FAHKAHATCHEE RIVER
FAHKAHATCHEE BAY
EAST RIVER

Figure XII-5. General Distribution and Mean Concentration of Green Filamentous Algae in Fahka Union and Fahkahatchee Bays, January 1972

Fahkahatchee Bay -	green filamentous algae	13,541 gm dry wt.
	grasses	9,756 gm dry wt.
	red macro-algae	3,371 gm dry wt.
Fahka Union Bay -	green filamentous algae	16,849 gm dry wt.
	grasses	776 gm dry wt.
	red macro-algae	192 gm dry wt.

A summary of the January 1972 standing crop biomass survey is provided in Appendix G.

In March, spot checks on standing crop biomass during the course of the benthic chamber work yielded an average concentration of 6.2 and 14.9 gm dry wt/m^2 for Fahka Union and Fahkahatchee Bays, recpectively. These values represent an average concentration of the combined grasses and red and green algae. Sampling was limited to those areas of the two bays designated in the January survey as supporting trace, medium, and heavy concentrations of plants.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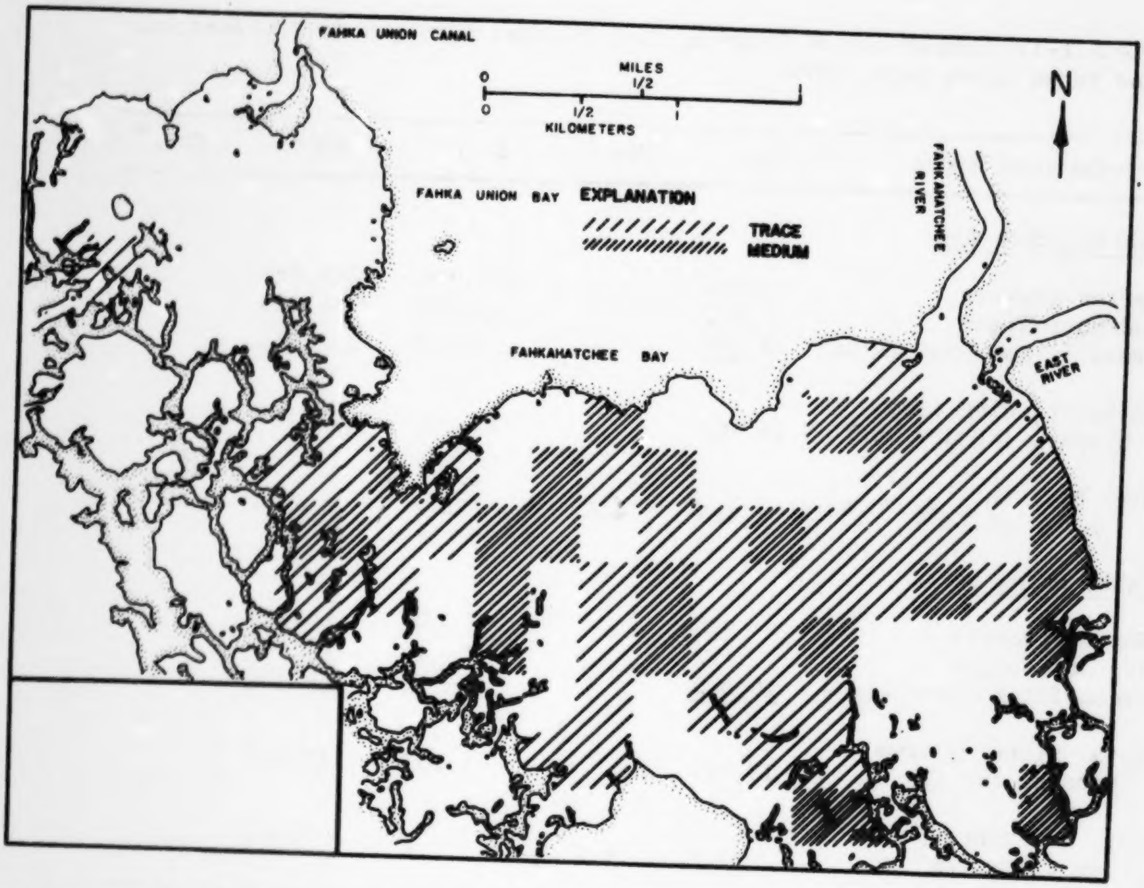
FAHKAHATCHEE RIVER
FAHKAHATCHEE BAY
EAST RIVER

Figure XII-6. General Distribution and Mean Concentration of Red Macro-Algae in Fahka Union and Fahkahatchee Bays, January 1972.

Major changes in total standing crop biomass occurred between July and September 1972 (Table XII-1). In Fahkahatchee Bay both marine grasses and red macro-algae showed steady increases in biomass whereas filamentous algae declined. Marine grasses totaled 169,930 kg in July and 245,685 kg in September; likewise, the red macro-algae increased from a total of 13,402 kg in July to 56,120 kg in the fall. Green filamentous algae decreased from a maximum in January to 1,817 kg in July and a low of 597 kg in September.

In Fahka Union Bay red macro-algae were the only plant type to show a steady increase in biomass from January to September. In July the standing crop of red macro-algae increased nearly 11 times over the total 192 kg reported for January. The September biomass exceeded by about 580 times the January estimate.

Little change occured with the marine grasses of Fahka Union Bay in July and September - 3,733 kg vs 3,788 kg, respectively; although, the two values were about 5 times that reported for January.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TRACE
MEDIUM
FAHKAHATCHEE RIVER
FAHKAHATCHEE BAY
EAST RIVER

Figure XII-7. General Distribution and Mean Concentration of Marine Grasses in Fahka Union and Fahkahatchee Bays, January 1972.

Unlike Fahkahatchee Bay, green filamentous algae in Fahka Union Bay first decreased in biomass to an apparent low of 9,238 kg in July but promptly increased to 15,472 kg in September -- a level comparable to estimates in January (16,849 kg).

The general distribution and centers of abundance of benthic vegetation in Fahka Union and Fahkahatchee Bays during the July and September surveys are shown in Figures XII-8, 9, 10, and 11. Three basic types of substrates characterized the two bays -- predominantly, mud, sand-mud mixes, and shell (Figure XII-12). The former substrate having the greatest representation of either bay, supported the greatest standing crop in July. In Fahka Union Bay, the mud substrate was colonized principally with red and green algae; whereas, in the other bay the mud bottom support mainly marine grasses. The details of standing crop biomass data vs substrate types are given in Appendices H, I, J, K, L and M.

Table XII-1. Comparison of Standing Crop Biomass Surveyed in Fahkahatchee and Fahka Union Bays, 1972.

Vegetational Types	Jan.	Mar.[a]	July	Sept.	Nov.[a]
Fahkahatchee Bay					
Marine grasses	9,756		169,930	245,685	
Red macroalgae	3,371		13,402	46,120	
Green filamentous algae	13,541		3,634	597	
Total standing crop biomass (kg dry wt.)	26,668		186,966	292,372	
Avg. bay conc. (gm dry wt./m^2)	3.6	14.9	25.2	39.3	75.6
Fahka Union Bay					
Marine grasses	776		3,733	3,788	
Red macroalgae	192		2,229	108,422	
Green filamentous algae	16,849		9,238	15,472	
Total standing crop biomass (kg dry wt.)	17,817		15,200	127,682	
Avg. bay conc. (gm dry wt./m^2	9.4	6.2	8.0	67.4	66.8

[a] Results of abbreviated surveys during GPP studies.

The immediate question at this point is why does the mud bottom of Fahka Union Bay support mainly a benthic community of algae and not a marine grass community such as found in Fahkahatchee Bay? Discussion of this point will be delayed until after the results of the gross productivity have been reported.

The abbreviated survey in November during the benthic chamber studies yield the following average plant biomass for the three plant types combined for Fahka Union and Fahkahatchee Bays: 66.8 and 75.6 gm dry wt/m^2, respectively. The November average for Fahka Union Bay would be about the same for the September survey. However, the November average for Fahkahatchee Bay would be nearly twice that determined for the September study.

In summary, Fahka Union Bay was characterized by a mud bottom which supported a benthic plant community primarily comprised of red and green algae. Standing crop biomass remained nearly steady for the first six months of the year, followed by an outburst of algal mass accumulation in the fall

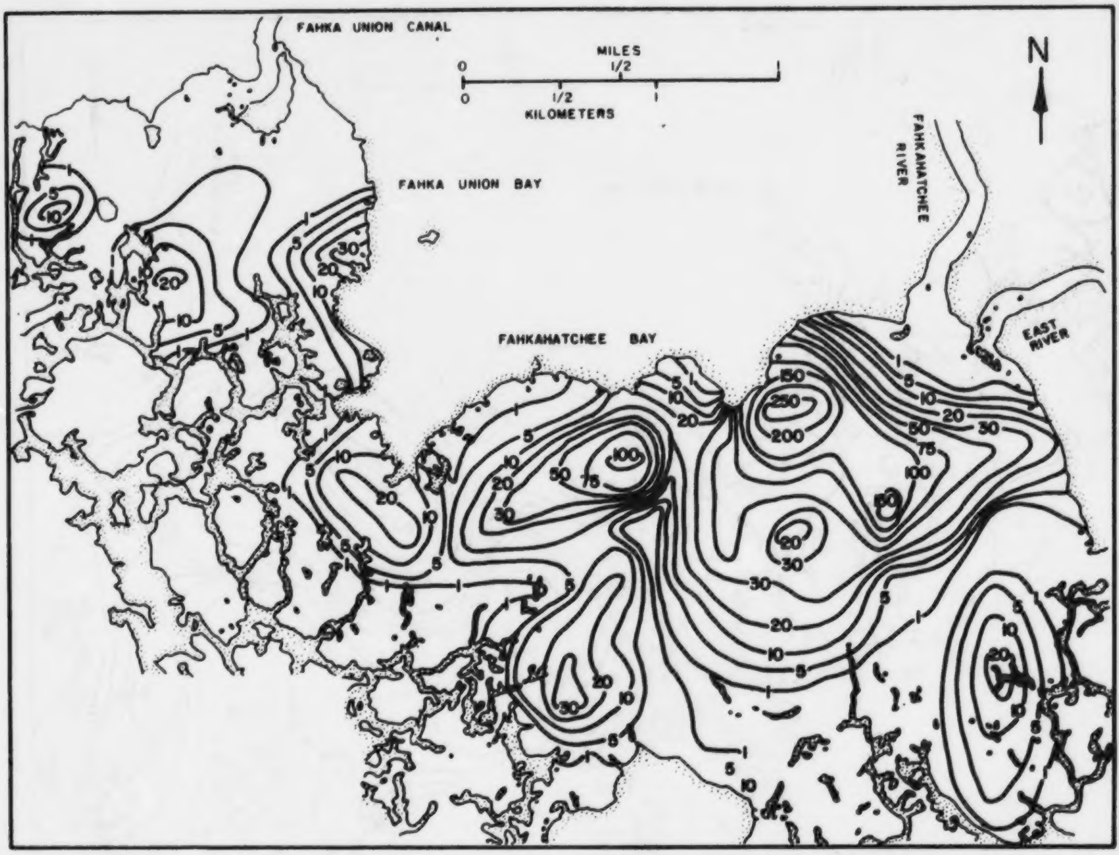

Figure XII-8. General Distribution and Centers of Abundance for Marine Grasses in Fahka Union and Fahkahatchee Bays, July 1972. Mean Concentration (gm Dry Wt/M^2)

months (Table XII-1). Fahkahatchee Bay, although it maintained a benthic plant community comprised mainly of algae in January, the marine grasses steadily increased in abundance and became the major plant community of the estuary. Unlike Fahka Union Bay, marine grasses were the principal plant type inhabiting the mud and mud-sand mixed substrate.

Light Extinction Studies

From February through April 1972 and from October 1972 to February 1973, surveys were conducted to assess light extinction characteristics of water masses in Fahka Union and Fahkahatchee Bays and to develop a model for predicting the visible light delivery to the benthic plant communities for photosynthesis.

During the two survey periods no difference in daytime turbidity (as measured by light extinction coefficient) could be reported between bays or between substrates within Fahkahatchee Bay. These judgments were based on results of analyses of variance using the reported mean extinction coefficients given in Appendices N, O and P.

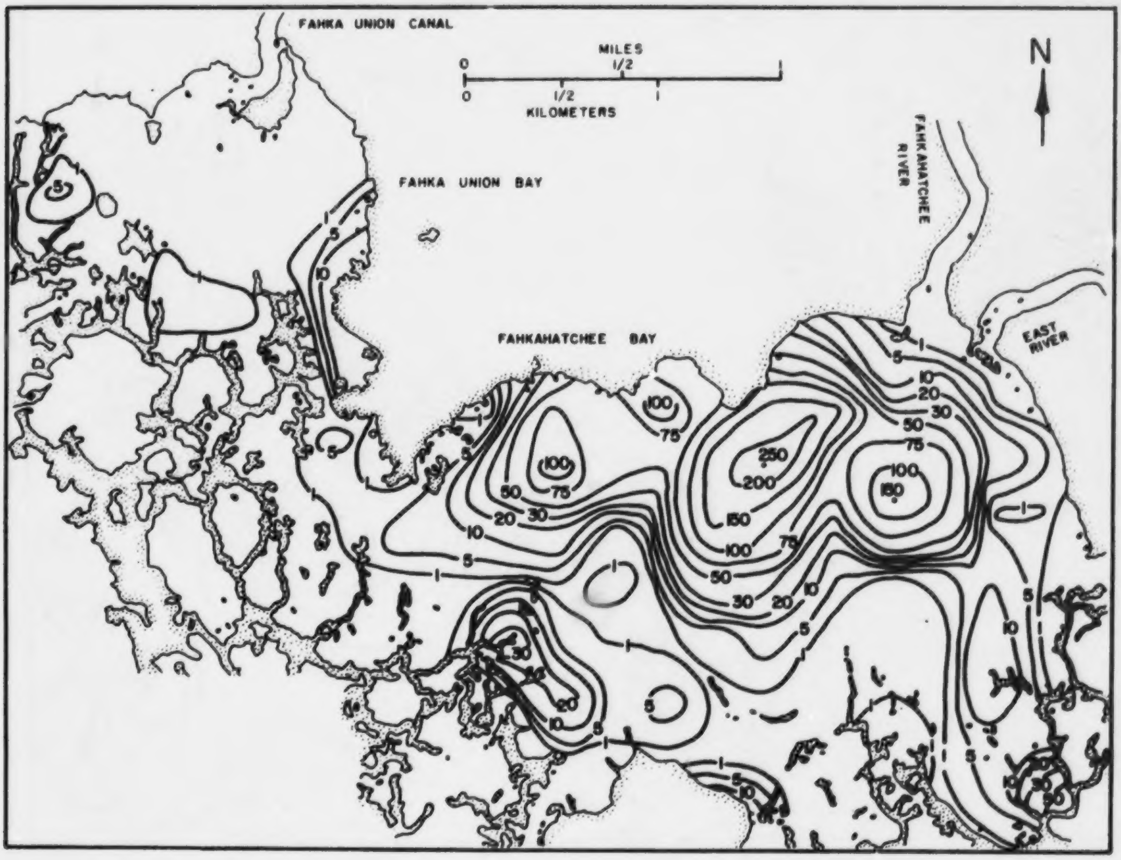
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Figure XII-9. General Distribution and Centers of Abundance for Marine Grasses in Fahka Union and Fahkahatchee Bays, September 1972. Mean Concentration (gm Dry Wt/m^2).

A linear regression model was developed for relating light extinction to depth. Based on 87 paired observations of light extinction coefficients (K) and depth of water column (Z), the following regression equation had a correlation coefficient of 0.64 with a t value of 6.00 at the 95 percent confidence level.

$$K = -1.40 \times 10^{-4} Z + 3.49 \times 10^{-2}$$

Where: K = Coefficient of Light Extinction (cm) at Bottom

Z = Depth (cm) of Water Column

Wind as an integrated factor with depth was viewed as the principal agent of vertical mixing in these shallow bays. Resuspension of sediments led to changes in the light scattering properties of the water; hence, the effects of wind on the diminution of light as it passed through the water column were manifested in the measurements of light extinction. The reported

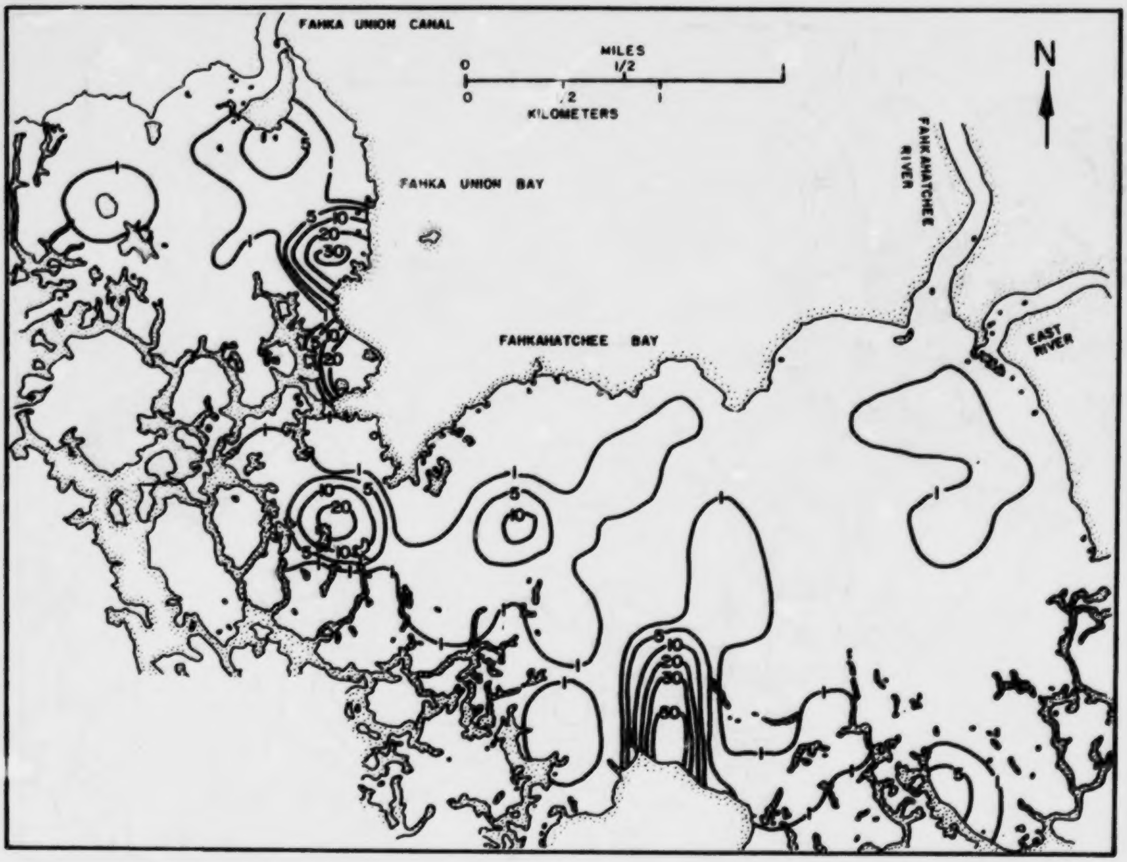

Figure XII-10. General Distribution and Centers of Abundance for Red and Green Algae in Fahka Union and Fahkahatchee Bays, July 1972. Mean Concentration (gm Dry Wt/m^2).

equation, therefore, includes wind, not as an implicated term, but as an integrated factor with depth.

Gross Primary Productivity Studies

Gross primary productivity (GPP) was assessed for benthic plant communities growing in Fahka Union and Fahkahatchee Bays during the months of February and March (spring) and again in October and November (fall) 1972. Using light and dark chambers, rates of benthic community oxygen demand and benthic plant production of oxygen were determined and are reported in Appendix Q.

From these data, rates of GPP and visible light transmission were converted to grams carbon per meter square per hour and langleys per hour, respectively, and reported in Tables XII-2 and 3. Data from these two tables were used to establish linear regression equations describing response of benthic GPP to visible light illumination at the bottom. The model used in these calculations is following:

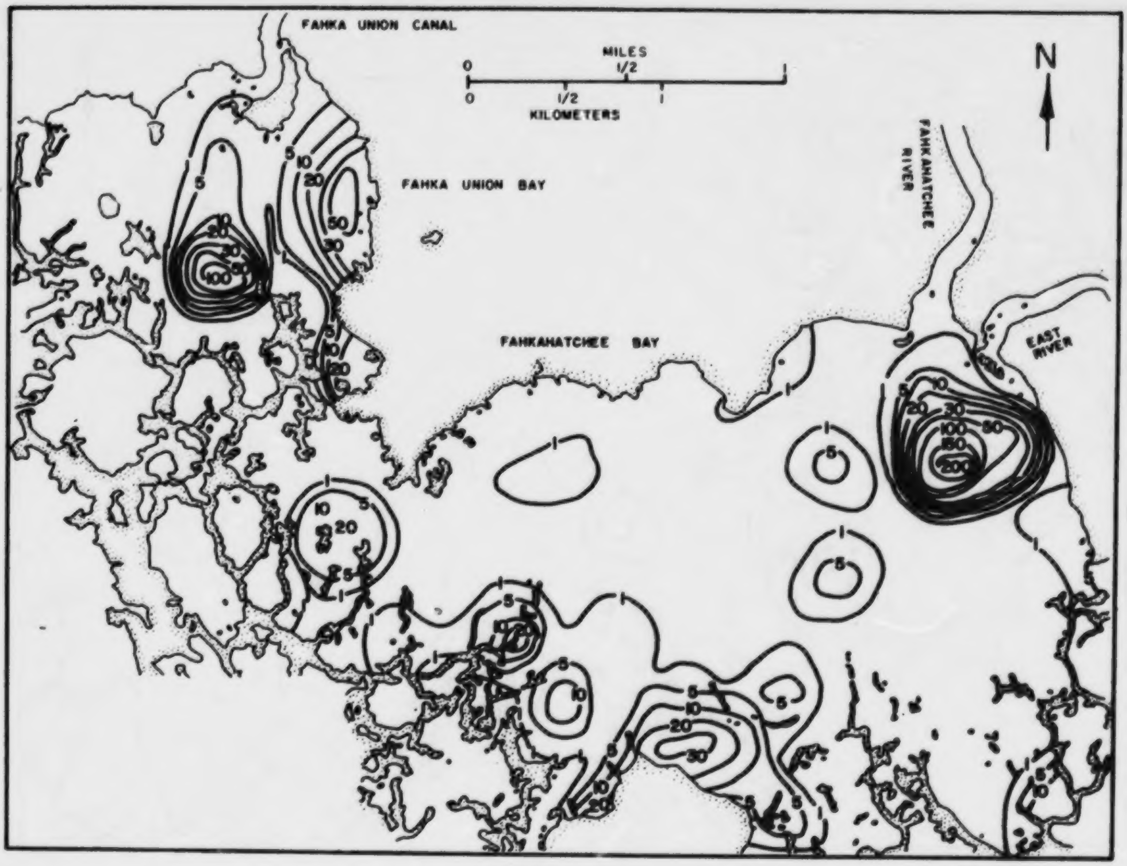
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Figure XII-11. General distribution and centers of abundance for red and green algae in Fahka Union and Fahkahatchee Bays, September 1972. Mean concentration (gm dry wt/m^2).

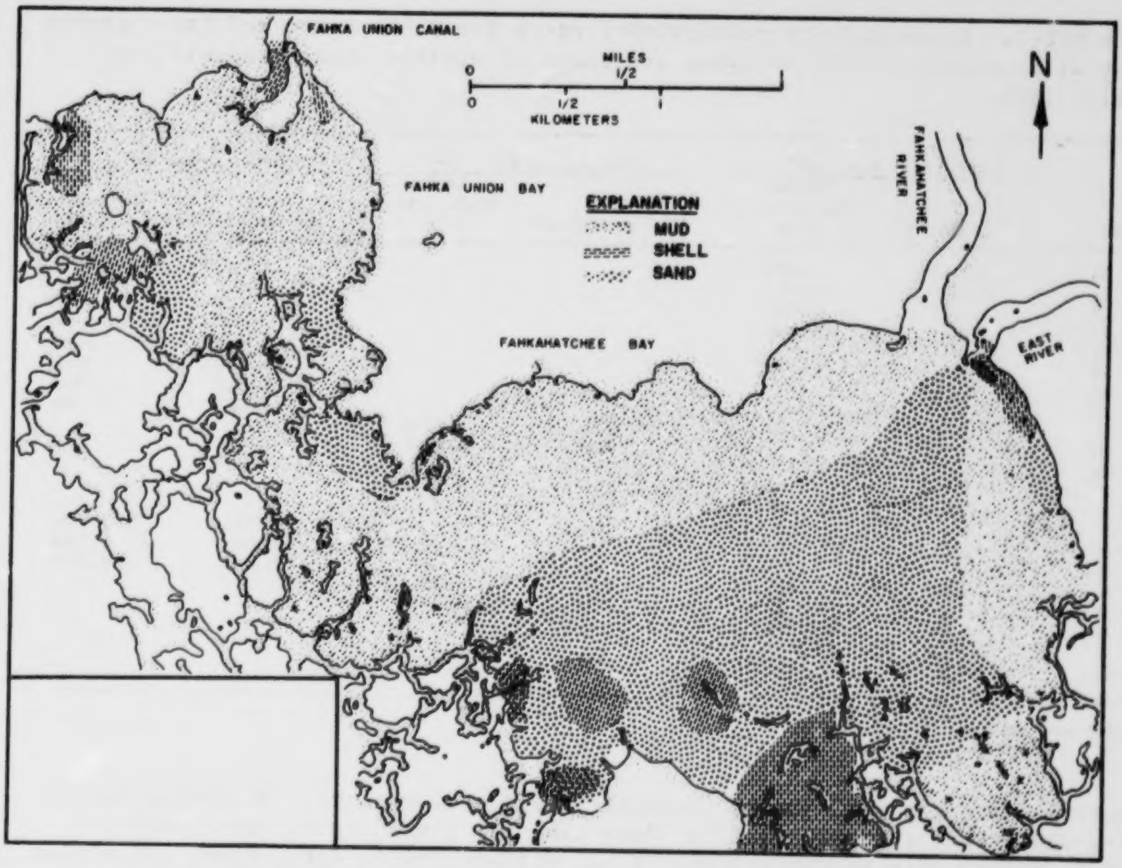
$$Y = mX + b$$

where: $Y = GPP\ (gm/C/m^2/hr)$, $b = Y$ intercept

$X =$ visible light (ly/hr)

$m =$ slope

Under survey conditions, the linearity of the GPP response to visible light transmission was good. In all cases, correlation coefficient of regression was greater than 0.88. At this point an examination of the reported regression equations (Figures XII-13 and 14) will indicate that in all cases the Y intercept is not equal to zero. Theoretically in a broad sense, the intercept should be zero on the basis that gross primary productivity ceases when light goes to zero. Unfortunately, theoretical consequences do not take into consideration possible threshold responses of productivity to light and also some unavoidable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EAST RIVER

Figure XII-12. Principal bottom substrate types characterizing Fahka Union and Fahkahatchee Bays, 1972.

Table XII-2. Gross primary productivity rates for Fahka Union and Fahkahatchee Bays with respect to bottom types and rates of visible light transmission, Spring 1972.

	Fahka Union Bay - MS[a]		Fahkahatchee Bay - SM[b]		Fahkahatchee Bay - MS[a]	
Date	GPP 10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr	GPP 10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr	10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr
Feb 15	0.9685	3.7512	-	-	-	-
Feb 15	0.2925	0.8562	-	-	-	-
Feb 15	0.2967	0.2141	-	-	-	-
Feb 16	0.9536	3.2351	-	-	-	-
Feb 17	-	-	0.8417	0.4362	-	-
Feb 18	-	-	1.0217	0.8179	1.5697	1.5632
Feb 18	-	-	-	-	8.0293	4.6073
Feb 18	-	-	-	-	7.4504	4.3338
Mar 7	-	-	2.7596	2.4000	-	-
Mar 7	-	-	1.9941	2.4338	-	-
Mar 8	-	-	-	-	4.1983	1.8184
Mar 8	-	-	-	-	4.4738	2.6936
Mar 8	-	-	-	-	3.2377	2.6172
Mar 24	-	-	0.1821	0.1894	-	-

a Mud-sand bottom
b Sand-mud bottom

Table XII-3. Gross primary productivity rates for Fahka Union and Fahkahatchee Bay with respect to bottom types and rates of visible light transmission, Fall, 1972.

Date	Fahka Union Bay - MS[a]		Fahkahatcher Bay - SM[b]		Fahkahatchee Bay - MS[a]	
	GPP 10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr	GPP 10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr	GPP 10^{-2} gm C/m^2/Hr	Bottom Light (Vis.) Ly/Hr
Oct 26	1.8143	1.8705	-	-	-	-
Oct 26	0.7023	2.9272	-	-	-	-
Oct 27	1.2240	2.4652	-	-	-	-
Oct 27	6.0312	3.4508	-	-	-	-
Oct 29	-	-	-	-	10.8240	3.2780
Oct 29	-	-	-	-	5.6770	1.9241
Oct 29	-	-	-	-	8.9704	3.1973
Oct 29	-	-	-	-	4.1876	1.4648
Oct 31	-	-	1.4224	5.0000	-	-
Oct 31	-	-	1.0159	4.6374	-	-
Oct 31	-	-	0.3944	3.4980	-	-
Oct 31	-	-	0.1236	1.1239	-	-
Nov 1	14.7264	6.8578	-	-	-	-
Nov 2	-	-	-	-	5.7566	1.3379
Nov 2	-	-	-	-	4.5679	1.3368
Nov 2	-	-	-	-	3.8794	0.8979
Nov 4	8.3206	5.9174	0.7032	2.9063	-	-
Nov 4	9.3121	6.3127	0.5931	1.9863	-	-
Nov 4	21.3636	13.6014	-	-	-	-
Nov 4	22.1880	12.2077	-	-	-	-
Nov 5	1.0017	1.6202	3.8276	7.4664	-	-

a Mud-sand bottom
b Sand-mud bottom

experimental error will always accompany field measurements. Reviewing Tables XII-2 and 3 will indicate that the data base for these curves were generated over a variety of test conditions: e.g., differences in date, time, and places of measurements. The effects of differences in depth, wind, and turbidity on productivity would then be mediated by incoming visible light to the chamber.

It is apparent from the reported response curves that gross primary productivity in Fahka Union Bay responded much more favorably to environmental conditions during the fall then in the spring. In Fahkahatchee Bay, however, gross productivity remained nearly the same in both seasons. Some environmental factors effecting these difference responses are considered in the forthcoming discussion.

Discussion

Our objectives in these studies were to establish estimates of the annual net and gross primary productivity for the benthic plant communities in Fahka Union and Fahkahatchee Bays and identify some specific environmental factors effecting plant community metabolism.

Light is the principal regulator of autotrophic metabolism. Hence, monthly estimates of gross productivity could be based on the average daily quantity of photosynthetic light delivered to the plant community over the month, providing other environmental factors are not limiting. The meaningfullness of this proposition, of course, depends on the existence of a quantitative relationship between light and gross photosynthesis. Nutrients can also be a major factor effecting photosynthesis. Not to be excluded from consideration are the plant species themselves and how they fit in the metabolic picture. These, although major factors, are but a few of the many possible considerations that can confound judgments regarding plant primary productivity.

Experimental results of our study have clearly demonstrated a quantitative response between benthic plant metabolism and light. Also shown was the degree to which turbidity governs the quantity of visible light at the bottoms in Fahka Union and Fahkahatchee Bays. Naturally, turbidity would be a secondary factor with respect to the total incoming solar radiation.

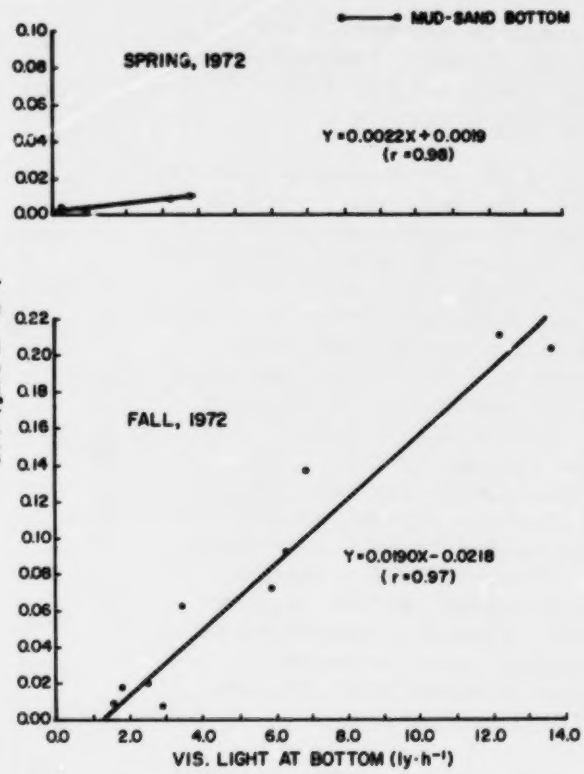


Figure XII-13. Regression of gross primary productivity on light with respect to bottom type and season for Fahka Union Bay, 1972.

Turbidity, as in our case measured by coefficient of light extinction, was a consequence of wind and depth interactions which can ultimately lead to resuspension of sediment. The previously reported equation $K = 1.40 \times 10^{-4} Z + 3.49 \times 10^{-2}$ provides a model from which estimates of light extinction coefficients can be calculated under given conditions of depth. By substitution of this expression into the light extinction model established in Beer's Law, the quantity of photosynthetic energy (langleys) available to the benthic plants can be determined for given depth and total solar radiations.

$$I = Io \cdot e^{-KZ}$$

where: I = quantity of photosynthetic light received at the bottom (langleys)

Io = quantity of photosynthetic light received at the water surface (langleys)

K = light extinction coefficient ($K = -1.40 \times 10^{-4} Z + 3.49 \times 10^{-2}$)

Z = depth of water (cm) over bottom

A complete expression for benthic light illuminations would be $I = I_0 \cdot e^{-(1.40 \times 10^{-4} Z + 3.49 \times 10^{-2}) Z}$.

From the preceding expression, the mean daily visible light (langleys/day) delivered to the benthic plant communities was calculated (Table XII-4). These data were based on monthly averages for daytime depths (0600 to 1800 hours) and total solar radiation. Inspection of Figure XII-15 reveals that the average benthic light illumination for both bays followed a general pattern of decreasing light from January to December 1972. Benthic plant gross production, however, generally proceeded at greater rates in November than in March 1972 (Figures XII-13 and 14).

A month by month estimate of productivity for the year was possible on the bases of linear interpolation over time of the slopes and intercepts derived from the spring and fall surveys. This operation yielded separate regression equations for each month. Each equation coupled with the respective mean light value given in Table XII-4 provide an estimate of mean daily gross productivity for each month of the study year (Table XII-5).

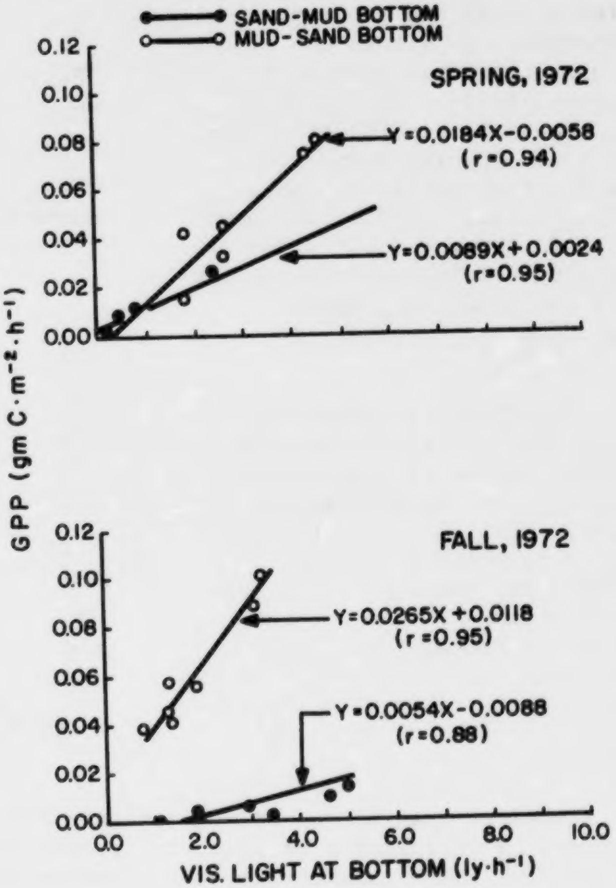


Figure XII-14. Regression of gross primary productivity on light with respect to bottom type and season for Fahkahatchee Bay, 1972.

A seasonal pattern emerges for gross productivity and the accumulation of biomass of the benthic algae in Fahka Union Bay (Figure-16). In the case of gross productivity, the steady increase from March to November appeared to be independent of the diminishing quantities of photosynthetic light indicated in Figure XII-15. Apparently, environmental factors other than light were stimulating an increase in gross productivity.

During the same time frame, an outburts in the accumulation of standing crop biomass occurred. The exact point in time at which this activity took place is difficult to ascertain, except to say that it occurred between the time of the July and September biomass surveys.

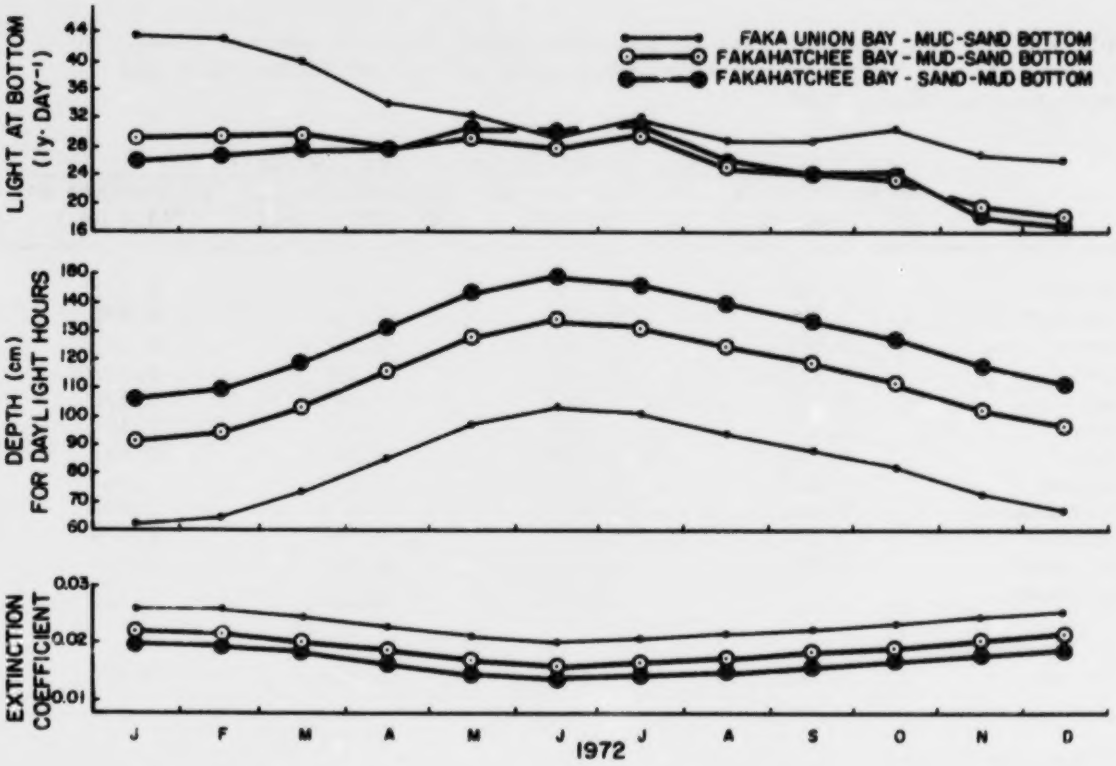


Figure XII-15. Monthly average bottom illumination and turbidity with respect to average daytime depths in Fahka Union and Fahkahatchee Bays, 1972.

Table XII-4. Calculated monthly means of depth during daylight hours, visible light transmission at bottoms, and light extinction coefficient, Fahka Union and Fahkahatchee Bays, 1972.

Month	Daily Mean Total Solar Radiation (ly)	Mean Depth (cm) During Daylight Hours			Visible Light Transmission at Bottom (ly/day)			Light Extinction Coefficient (cm) at Depth		
		FU-MS[a]	FB-MS[b]	FB-SM[c]	FU-MS[a]	FB-MS[b]	FB-SM[c]	FU-MS[a]	FB-MS[b]	FB-SM[c]
January	450.0	61.0	91.4	106.7	43.7	28.9	25.9	0.0264	0.0221	0.0200
February	468.2	64.0	94.5	109.7	43.1	29.3	26.6	0.0259	0.0217	0.0195
March	502.9	73.2	103.6	118.9	40.1	29.5	27.8	0.0247	0.0204	0.0182
April	497.0	85.3	115.8	131.1	34.0	27.7	27.5	0.0230	0.0187	0.0165
May	527.6	97.5	128.0	143.3	32.2	29.1	30.5	0.0210	0.0170	0.0148
June	498.9	103.6	134.1	149.4	29.2	27.8	29.9	0.0204	0.0161	0.0140
July	530.4	100.6	131.1	146.3	31.7	29.4	31.2	0.0208	0.0165	0.0144
August	458.9	94.5	125.0	140.2	28.7	25.3	26.1	0.0217	0.0174	0.0153
September	436.2	88.4	118.9	134.1	28.9	24.1	24.3	0.0225	0.0183	0.0161
October	431.5	82.3	112.8	128.0	30.5	24.2	23.8	0.0234	0.0191	0.0170
November	333.6	73.1	103.6	118.9	26.6	19.5	18.4	0.0247	0.0204	0.0182
December	299.1	67.1	97.5	112.8	26.2	18.2	16.8	0.0255	0.0213	0.0191

[a] Fahka Union Bay - mud-sand bottom

[b] Fahkahatchee Bay - mud-sand bottom

[c] Fahkahatchee Bay - sand-bottom

Table XII-5. Average daily gross primary productivity of benthic plant communities established on the mud and sand bottoms of Fahka Union and Fahkahatchee Bays, 1972.

Month	Avg. daily GPP by mo. (gm C/m^2/day)			
	Fahka Union Bay MS[a] (143.1 ha.)	Fahkahatchee Bay MS[a] (386.8 ha.)	Fahkahatchee Bay SM[b] (299.6 ha.)	Fahkahatchee Bay (743.2 ha.)
January	0.349	0.650	0.183	0.413
February	0.206	0.576	0.212	0.385
March	0.069	0.537	0.250	0.381
April	0.110	0.534	0.235	0.372
May	0.153	0.592	0.244	0.406
June	0.183	0.596	0.225	0.401
July	0.253	0.662	0.217	0.432
August	0.266	0.600	0.170	0.380
September	0.311	0.598	0.147	0.370
October	0.376	0.627	0.131	0.379
November	0.366	0.529	0.090	0.311
December	0.281	0.453	0.010	0.277
Daily average for year	0.243	0.580	0.176	0.376

[a] Mud-sand bottom

[b] Sand-mud bottom

Algal populations can be characterized by a rapid turnover rate opposed to vascular plants. Under optimum environmental conditions of light, nutrient, temperature, and possibly salinity, an algal community can enter into an exponential growth phase that may occur over a few days; a phenomenon frequently associated with algal blooms.

Thus, the question is whether or not the fall pulse of benthic algal productivity was related to seasonal freshwater discharges from Fahka Union Canal or Fahka Union Bay.

The view that the fall pulse in productivity was stimulated by nutrients entering the bay via the canal has certain appeal (Figure XII-16); although, close examination of the given data indicates that the community was slow, or failed to respond to the initial slug of nutrients arriving at the bay in June when hurricane Agnes passed through the region. Following the "big flush," nutrient loading to the bay proceeded steadily to a peak (at least nitrogen) in September when the greatest standing crop biomass of algae was recorded. Likewise, gross productivity followed a trend fairly similar to nutrient loading.

On the other hand, the fall pulse in productivity may possibly be an inherent growth property of the community and unrelated to seasonal discharges of the canal. Returning to Table XII-1, it is apparent that in both bays a fall increase in benthic algal standing crop occurred. For example, in Fahkahatchee Bay, the green and red algae combined showed a 100 percent increase in biomass from July to September. During the same period, the algal community of Fahka Union Bay increased many times.

Nutrient loading of Fahkahatchee Bay was not as clearly evident as the case in Fahka Union Bay. The former bay receives the major share of its freshwater input from upland sources such as Fahkahatchee Strand (Chapter VII, Figures VII-8 and 9). During the study year, measurable surface water flow across U.S. 41 (Tamiami Trail) failed to develop. Hence, the bay was dependent for its major freshwater supply on rainfall accumulation and runoff in the marsh lands south of U.S. 41.

The potential of the uplands as a source of nutrients to the bay by way of runoff is evident in Figure XII-17 where nutrient transport across Janes Drive is illustrated. Under normal hydrological conditions, a similar transport picture would be expected at U.S. 41 and in the freshwater reaches of the Fahkahatchee River and also the East River. Both rivers lead to the bay. Nutrient enrichment of the bay was somewhat clarified in the water chemistry section (Chapter X). Total Kjeldahl nitrogen concentrations reported for Fahkahatchee River were on the average twice that observed in the bay (Figure X-10).

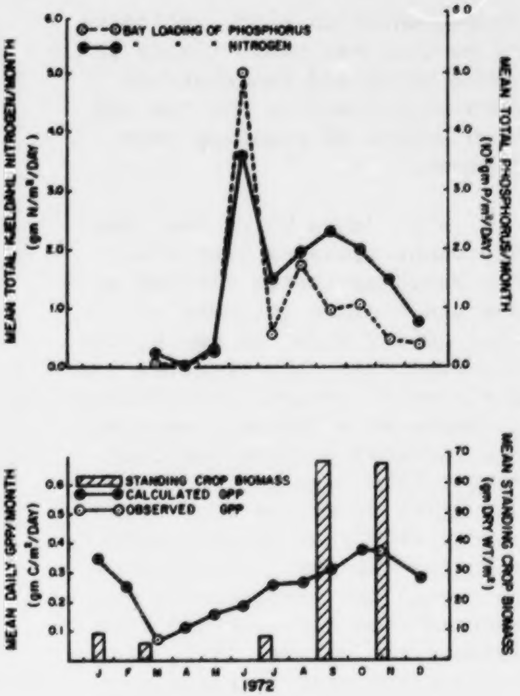


Figure XII-16. Benthic plant productivity interrelationship and daily nitrogen and phosphorus loading per month, Fahka Union Bay, 1972.

For Fahkahatchee Bay, measured gross productivity rates in March were nearly the same as reported in November. The yearly pattern, however, shows a slight but steady decrease in gross productivity (Figure XII-17). The opposite trend was true for the accumulation of plant biomass. The marine grasses increased their standing crop biomass over the year at a steady rate and peaked in the fall of the year. It is quite possible that after the community approached its peak biomass, the plants were only photosynthesizing at a maintenance rate; hence a slight decline in production rates would not be totally unexpected.

Measurements of net productivity when assessed by biomass accumulation techniques represents, at best, a minimal estimate of the parameter. This is true because the estimates fail to account for plant carbon losses to respiration, grazing, and leaf or cell mass turnover. The latter consideration would be extremely salient when dealing with an algal community. With these consequences in mind, estimates of benthic net productivity in Fahka Union and Fahkahatchee Bays were based on the low and high points of standing crop biomass.

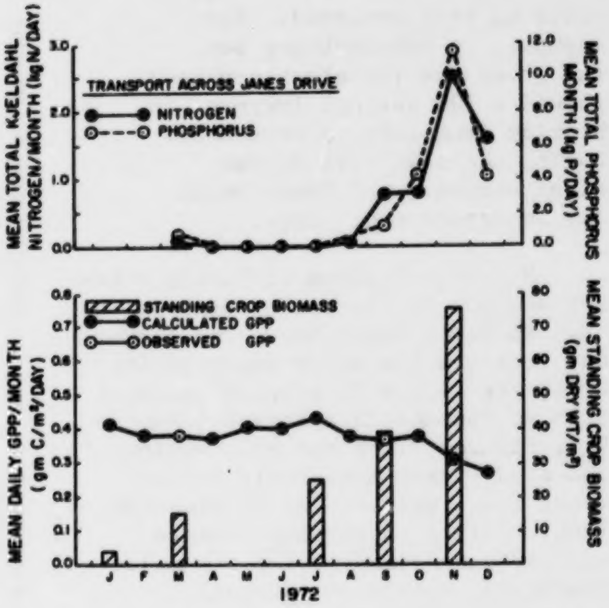


Figure XII-17. Nutrient transport across Janes Scenic Drive and benthic plant productivity, Fahkahatchee Bay, 1972.

With Fahka Union Bay, the September standing crop minus the March estimates yielded an average biomass increase of 61.2 gm dry wt/m^2 of bay bottom. Although this gain occurred over a six month period, nevertheless, it represents the only measured net increase for the sampling year. This figure divided by 365 gives an estimate of 0.168 gm dry wt/m^2/day as net production for the bay. An estimate of annual net productivity for Fahkahatchee Bay extended from January to November 1972, and the average gain in standing crop biomass was 0.197 gm dry wt/m^2/day. Summaries of average daily rates of primary productivity are given in Table XII-6 and are based on values reported in Table XII-5 and the above estimates of net production rates. A comparison of the two estimates of net productivity figures would tend to indicate that the two bays supported similar plant communities in terms of net productivity capabilities. However, Fahka Union Bay supported mainly benthic algae whereas Fahkahatchee Bay maintained marine grasses.

Table XII-6. Average daily rates of primary production for the benthic plant communities associated with Fahka Union and Fahkahatchee Bays during 1972.

	Fahka Union Bay		Fahkahatchee Bay	
	gm C/m^2/day	gm dry wt/m^2/day	gm C/m^2/day	gm dry wt/m^2/day
Gross productivity	0.243		0.376	
Net productivity		0.168		0.197

a Fahka Union Bay total bottom area of 189.3 ha.
Fahkahatchee Bay total bottom area of 743.2 ha.

Reasons for the difference in plant community types between the two bays are not obvious. First, turbidity of the waters as a factor has little appeal.

As indicated earlier, we found little differences in the turbidity regimen of the two bays. Possibly, water depth could have been a contributing factor to the disparity in community types.

Fahka Union, on the average, was nearly 30 percent shallower than Fahkahatchee Bay. A review of Figure XII-15 will show that average depths during daylight hours were always greater than 60 cm in Fahka Union Bay. This depth is not uncommon to marine grass beds in the Ten Thousand Island region (B. Yokel, personal communication).

An examination of the information previously reported on sediment characteristics indicates that the bottom of Fahka Union Bay served to a greater degree as a sink for heavy metals. For example, nickel, zinc, lead, cadmium, copper, chromium, and arsenic were nearly two to three times greater in concentration in sediments in Fahka Union than in Fahkahatchee Bays (Chapter XI). The reverse was true for metal concentrations in the water columns of the two bays. Concnetrations of nickel, zinc, lead, cadmium, and copper were consistently greater in waters of Fahkahatchee Bay than Fahka Union Bay. From a toxicological viewpoint, possibly the concentrations of metals in the sediments of Fahka Union Bay inhibited development and growth of marine grasses. Marine grasses are vascular plants and maintain a root system which derives much of their nutrient requirements from the sediment whereas algae obtain their nutrients principally from the water.

Finally, we might hypothesize that the additional nutrient loading of Fahka Union Bay from the canal stimulates algal growth to a level of standing crop biomass that leads to a smothering or shading out of the vascular plants. This possibility has merit when considering the scheduling of nutrient input to both bays.

During most of the winter months (dry season), Fahka Union Bay received nutrients via freshwater discharges from the Fahka Union Canal while Fahkahatchee Bay received almost no inputs of nutrients from the uplands. In both bays a winter die back of the grasses occurred, thus, leaving the major portion of the winter standing crop biomass as algae (review Table XII-1). With the approach of the spring growing season, the algae in Fahka Union had the competitive edge for colonization of the bay because of additional nutrients provided by the canal and reduced competition for these nutrients in the absence of marine grasses.

SALT MARSH AND MANGROVE METABOLISM

Introduction

The functional properties of mangrove ecosystems in south Florida has recently become a topic of extensive analytical investigation. Studies by Heald (1971), and Odum (1971), have linked in quantitative terms the regional role of mangrove forests in the detrital-based economy of an estuary. Mangrove detritus is ultimately derived from the communities' ability to produce organic matter. Limitations of this work process are governed by numerous environmental controls such as light and nutrients.

The nutrient budget supporting mangrove metabolism in the region may be ultimately derived from nutrient stores generated in the freshwater uplands.

This same view is indicated in recently reported work on mangrove metabolism by Lugo, et al. (in press). Overland flow of fresh water serves as the principal transporter of nutrients from the interior regions to the tidal zone. As fresh water seeks its way to the Gulf, its nutrient load is relieved through biotic uptake and dilution.

The object of this study was to determine the response of mangrove productivity to a decreasing freshwater gradient which implies that across this gradient, nutrient availability for plant metabolism decreased with increasing chloride concentrations. An additional purpose of this study was to assess saltgrass marsh community productivity in response to increasing levels of chlorides.

Study Area and Site Locations

Two areas were selected for study on the basis of accessibility with equipment and proximity to a freshwater gradient. The Fahka Union River drainage system served as the principal area of investigation (Figure XII-18). The upper reaches of the river receive surface runoff from two freshwater sources, rainfall in the immediate salt marsh regions, and surface water runoff from the upland terrestrial systems north of U.S. 41. In both cases, the river serves as a tidal waterway for collection and delivery of nutrient-bearing fresh water to the estuary. The second area of study was Fahkahatchee Bay, which represents the final stage, or receiving point (prior to the Gulf), for natural freshwater runoff. The Fahkahatchee River and the East River discharge to this bay and share the same drainage features as Fahka Union River. The four study sites were positioned along a north to south freshwater gradient (Figure XII-18). For reason of limited accessibility, the Fahkahatchee River drainage was excluded from this study. The northern most site (Station D) represented the area of greatest freshwater concentration, while the southern most location (Station G) represented the least concentration. A general description of each study site location follows:

Station D. The general habitat was composed of saltgrass marshes and scattered stands of mature mangroves. Both communities bordered a shallow brackish lake, whose water level varied slightly with tidal amplitudes. Tidal water level changes ranged from about 8 to 16 cm.

The mangrove community followed a general landward zonation pattern along one side of the lake. Red mangroves predominated at the water's edge. Their proproots and often the base of their trunks were subject to semidiurnal tidal flushing. The interior zone was higher ground, and was mainly occupied by black mangroves and scattered individuals of buttonwood. Regular flushing of this zone was not apparent.

The saltmarsh community occupied the shore and landward areas opposite to the mangrove community. The marsh at this point in the Fahka Union River basin was subject to daily flooding - mainly a consequence of tidal amplitude. The area supported a variety of semiaquatic plants that are identified in Chapter XIII.

Station E. At this point in the basin, the river channel was well defined and ranged from 5 to 15 meters in width. Colonizing the river's edge were

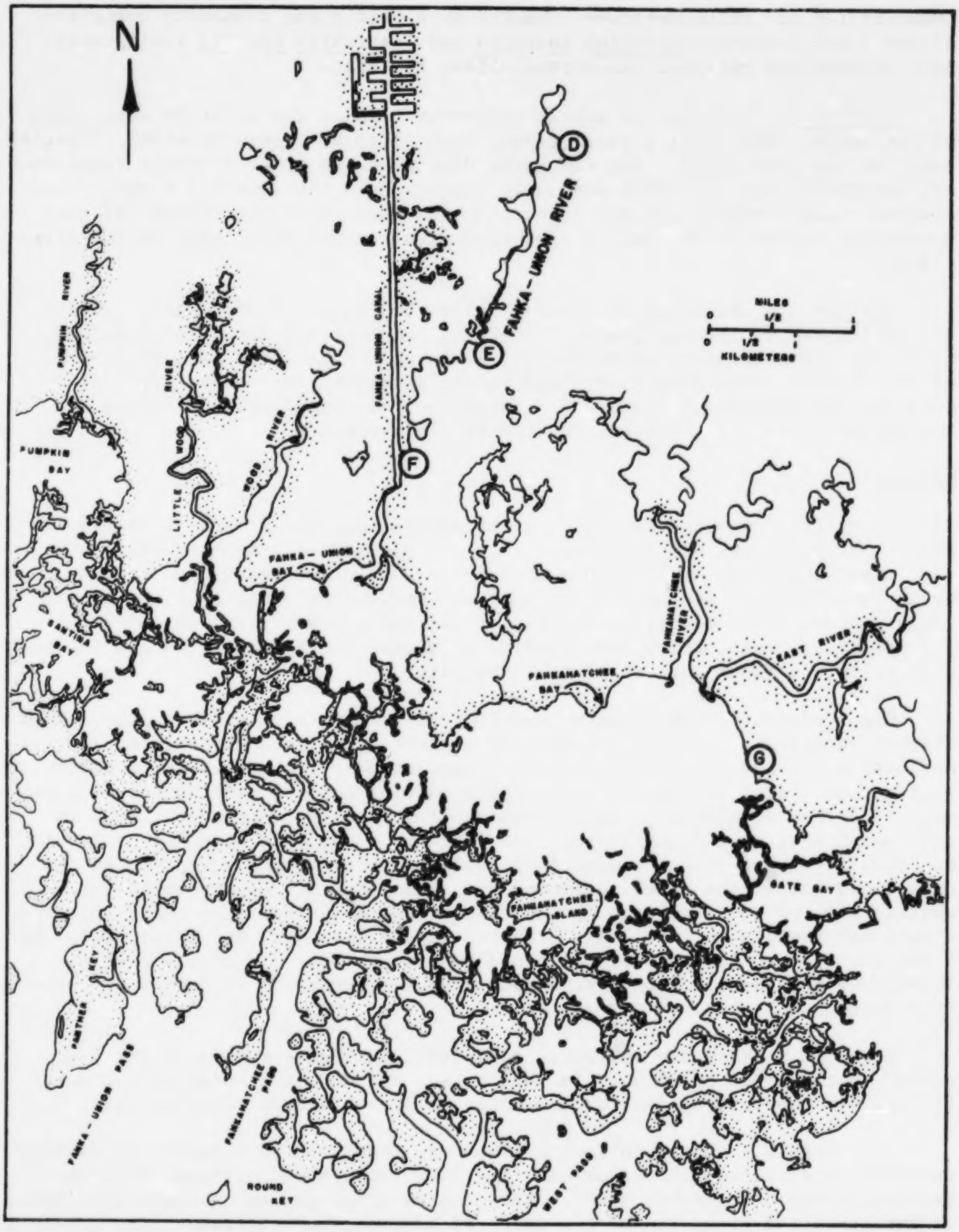

N
D
FAHKA - UNION RIVER
E
FAHKA - UNION CANAL
F
MILES
0 1/2 1
0 1/2 1
KILOMETERS
PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAHKA - UNION BAY
SANTINA BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
G
GATE BAY
FAHKAHATCHEE ISLAND
PANTHER KEY
FAHKA - UNION PASS
FAHKAHATCHEE PASS
ROUND KEY
WEST PASS

Figure XII-18. Station locations for the study of mangrove and salt marsh community metabolism, 1972.

immature red and white mangroves, backed by a salt marsh community comprised of two plant species - Spartina spartina and Distichlis spicata (saltgrass). Both communities received semidiurnal tidal flushing.

Station F. A forest of mature mangroves flanked the river in this reach of the basin. The river channel ranged from 15 to 20 meters in width. Species zonation was pronounced. Red mangroves dominated the river frontage vegetation, but coexisted with the black and white mangroves in the interior zones. Semidiurnal tidal flushing did not appear to be a characteristic feature of the community, except in the case of red mangroves occupying the edge of the river channel.

Station G. The study site was situated at the mouth of a small tidal stream located on the northeastern shore of Fahkahatchee Bay. The mainland mangroves represented a mature forest. This particular area supported some of the largest sized mangroves found in the Fahkahatchee region. Species zonation was similar to Station F. However, semidiurnal tidal flushing of the forest floor was a typical feature of the community.

Methods

Plant taxonomic features of the communities are dealt with in Chapter XIII. Net and gross primary productivity of manland mangrove forests and salt marshes were determined from measurements of plant uptake and release of carbon dioxide. At this point, only an abbreviated version of the methodology employed is presented. Details of the subject are given in Appendix R. All metabolic measurements were limited to above-ground vegetation and included only principal plant species of the community.

Clear plastic chambers were used to isolate a portion of the plant. Each chamber received a continuous supply of ambient air at a known rate of flow and carbon dioxide concentration. The chambers were fitted with an exhaust port at the distal end of enclosure where exiting air was sampled for measurement of carbon dioxide concentrations. In the case of groundcover, such as salt marsh plants, a rigid cylindrical chamber (1 meter in diameter by 1 meter in height) covered with a clear, thin (0.05 cm) polyacetate material was set over a segment of the plant community and sealed to the substratum by the cutting edge of the chamber. When working with woody plants, a clear plastic sheath was used to enclose leafy branches, trunk segments, and proproots. The fresh air flow to the chamber ballooned the sheath into a semi-rigid form. These sheaths, when inflated, measured about 1.2 meters in length by 0.6 meters in diameter.

Both the polyacetate and plastic material were assessed for filtering effect on the light spectrum. In both cases, the material acted as a neutral filter, but suppressed light transmission by approximately three percent.

The fresh air supply to each chamber was regulated to maintain an average turnover rate of about five per minute. This rate proved optimum for maintaining across the chamber a CO_2 concentration (ppm) gradient within the limits of detection and precision of the infrared gas analyzer employed. The gradient was usually fess than five ppm. This turnover rate also proved effective in controlling air temperatures within the chambers. In all cases, the temperature differential between ambient air and air exhausting from the chamber remained less than 4°C, and usually ranged from 2° to 3°C.

Plant photosynthesis was determined by measuring the decrease in the chamber CO_2 gradient, and respiration rate was determined from measured increases in the gradient. These changes were recorded at hourly intervals over a 24-hour period. In most cases, four chambers were deployed. The CO_2 analyzer received daily calibration by introducing a known concentration of carbon dioxide to the detection system.

Assessment of plant transpiration was planned for this study but at the time electronic problems with the measuring devices prevented determinations.

Productivity and respiration values are reported as totals derived from integration of hourly rates over a complete diurnal period. Salt marsh productivity is reported as per unit land area of the community, while mangrove productivity is given per unit area of metabolic surface, e.g. leaf, trunk, and proproot area. To make productivity comparisons between species or communities would be inappropriate unless based on per unit land area. To render the initial data comparable, the mangrove metabolic values must be multiplied by the appropriate land area index (e.g. total metabolic surface area per unit land area). Indices for making these conversions were obtained from other work. Their implementation into our study is discussed later in the report.

These metabolic studies were conducted over the period from November 17 to December 21, 1972. To establish the freshwater regime at each of the metabolic sites, chloride concentrations were determined for surface water and soil solutions. When possible, an automatic, sequential sampler was used to collect hourly samples over a 24-hour period. In the case of soil waters, a perforated casing was inserted into the soil to a depth of approximately 0.75 meters. Seepage water was sampled in the same manner as above. In the absence of the automatic sampler, quasi-synoptic samples were obtained. During the course of the metabolic studies total solar radiation was recorded with a pyrheliometer.

All studies were conducted from a 12 by 38 foot pontoon barge equipped with an outborad motor. At each station, the barge was motored into position and securely anchored next to the plant community to be studied. Tents erected on the barge served as a base of operation and as shelters for the metabolic equipment.

Results

Station D, upper Fahka Union River, represented the least saline region of the drainage system in our study of mangroves. Soil water chlorides for the study site ranged in concentrations from 4.6 ppt to 5.0 ppt and averaged 4.9 ppt over the 24-hour sampling period. Simultaneously, surface water chlorides ranged from 4.4 ppt to 4.8 ppt and averaged 4.7 ppt.

Twenty diurnal rates of photosynthesis and respiration were measured over the period of November 26 to December 8, 1972. The saltmarsh community hosted several plant species but restricted accessibility with the equipment limited our study efforts to the following species: *Spartina spartina*, *Eleocharis cellulosa*, and *Distichlis spicata* (saltgrass). Results of the metabolic measurements are reported in Table XII-7. To provide a common basis for comparibility, the reported net primary productivity and respiration rates

Table XII-7. Results of plant metabolic studies to determine primary production of the salt marsh plant species associated with the upper Fahka Union River basin, Station D, 1972.

Date (1972)	Vegetation	Chamber Biomass Composition gm/m² (Ash Free Wt.) Total	Green Lvs.	Above Ground Dead	Roots	Total Solar Radiation ly/day	NPP_{Lp} $\frac{gm\ C}{m^2\cdot Lp}$	R_{Dp} $\frac{gm\ C}{m^2\cdot Dp}$	NPP_d $\frac{gm\ C}{m^2\cdot d}$	R_d $\frac{gm\ C}{m^2\cdot d}$	GPP_d $\frac{gm\ C}{m^2\cdot d}$
Nov 27	Spartina	1,451.6	531.8	324.8	595.0	339	0.860	0.263	0.597	0.477	1.074
Nov 28	Spartina	1,451.6	531.8	324.8	595.0	313	0.777	0.649	0.128	1.176	1.304
Nov 29	Spartina	1,451.6	531.8	324.8	595.0	360	1.044	0.807	0.236	1.462	1.698
Nov 27	Spartina	1,762.1	813.9	541.5	406.7	400	1.196	0.572	0.624	1.035	1.659
Nov 28	Spartina	1,762.1	813.9	541.5	406.7	412	1.497	0.714	0.784	1.293	2.076
Nov 27	Eleocharis	688.4	92.8	52.4	543.2	339	0.674	0.387	0.287	0.702	0.988
Nov 28	Eleocharis	688.4	92.8	52.4	543.2	313	0.625	0.572	0.053	1.037	1.090
Nov 27	Distichlis[b]	3,094.6	551.2	856.8	1,686.6	351	1.646	0.735	0.911	1.331	2.242
Nov 28	Distichlis[b]	3,094.6	551.2	856.8	1,686.6	325	1.700	0.875	0.824	1.585	2.410
Nov 29	Distichlis[b]	3,094.6	551.2	856.8	1,686.6	373	1.794	0.670	1.124	1.214	2.338

[a] NPP - net primary production
R - respiration
GPP - gross primary production
L_p - photoperiod
D_p - dark period (13.2 hours)
d - 24 hour day

[b] Saltgrass

requires normalization for differences in solar radiation received and chambered biomass. Average gross production or respiration rates for the chambered plant component can be derived from the following relationships:

$$\frac{\sum_{n}\left[\dfrac{NPP_{Lp}\cdot\overline{ly}\cdot\dfrac{\Sigma Bo_{n}}{N}}{ly_{o}\cdot Bo}\right]}{N}-\frac{\sum_{n}\dfrac{R_{Dp}\cdot\dfrac{\Sigma Bo_{n}}{N}}{Bo}}{N}=\overline{NPP}_{24}$$

$$\frac{\sum_{n}\left[\dfrac{24\cdot R_{Dp}\cdot\dfrac{\Sigma Bo_{n}}{N}}{Dp\cdot Bo}\right]}{N}=\overline{R}_{24}$$

$$\overline{GPP}=\overline{NPP}_{24}+\overline{R}_{24}$$

where

NPP_{Lp} = total observed net productivity for photoperiod (gm C/m²/Lp)

Bo = observed chamber biomass (on carbon fixation rates, Bo refers to green leaves and for respiration rates, Bo refers to total biomass)

ly_o = observed total solar radiation for day

N = number of replications ($N \geq 1$)

$\overline{ly}$ = daily average (293 langleys) of total solar radiation for November 17 through December 21, 1972

R_{Dp} = total observed nighttime respiration

Dp = dark period in hours

24 hrs = complete day

$\overline{NPP}_{24}$ = systems mean net productivity for day (gm C/m^2/day) (Figure XII-19; $NPP_{24} = 1 - 2$)

$\overline{R}_{24}$ = systems mean respiration for day (gm C/m^2/day) (Figure XII-19; $R_{24} = 2 + 3$)

$\overline{GPP}$ = systems mean gross productivity for day (gm C/m^2/day)

Figure XII-19 represents diagrammatically the general metabolic scheme for plant photosynthesis and respiration over a complete diurnal period.

Based on the above relationships, an average daily production and respiration were calculated for the three saltmarsh plant species studies and reported in Table XII-8.

Results of the mangrove metabolic measurements at Station D are presented in Table XII-9. As noted, measurements were limited to red and black mangrove and buttonwood (Rhizophora mangle, Avicennia nitida, and Conocarpus erecta, respectively). White mangroves (Laguncularia racemosa) were absent from this community. The normalization procedures outlined above were also applicable to the mangrove data except that the area of metabolic surface, e.g. leaf surface area, replaces the term for observed biomass.

Average productivity and respiration rates for selected components of the community are presented in Table XII-10.

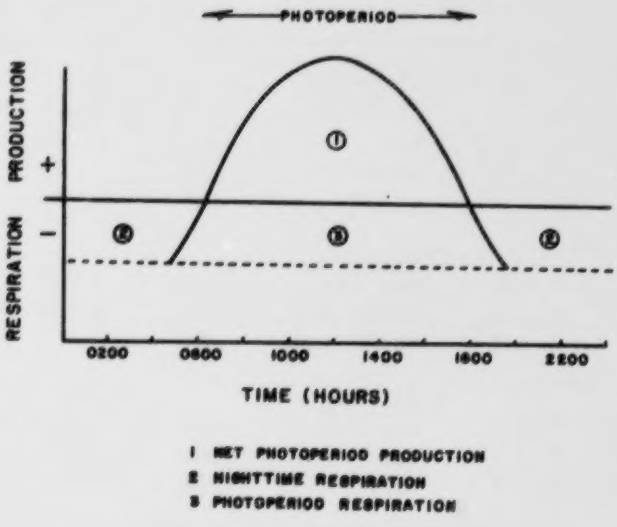


Figure XII-19. Schematic of diurnal response of plant metabolism.

Table XII-8. Mean rates of productivity and respiration for three species of plants characteristic of the saltgrass marshes associated with the upper reaches of the Fahka Union River, Station D, 1972.

Plant	Chamber Biomass[a], Ash Free Wt. (gm/m^2) Total	Green Lvs.	Above-Ground Dead	Roots	Metabolism (gm C/m^2/day)[b] GPP_{24}	NPP_{24}	R_{24}
Distichlis sp.	3,094.6	551.2	856.8	1,686.6	2.06	0.679	1.38
Spartina sp.	1,606.8	672.8	433.2	500.8	1.41	0.293	1.12
Eleocharis sp.	688.4	92.8	52.4	543.2	0.976	0.104	0.872

a Average of two replications for Spartina sp.
b rates normalized for biomass and light.

Table XII-9. Results of plant metabolic studies conducted to determine primary production of the mangroves associated with the upper Fahka Union River, Station D, 1972.

Date (1972)	Vegetation	Total Solar Radiation ly/Lp	Plant Metabolism[a] NPP_{Lp} $\frac{gm\ C}{m^2 \cdot Lp}$	R_{Dp} $\frac{gm\ C}{m^2 \cdot Dp}$	NPP_d $\frac{gm\ C}{m^2 \cdot d}$	R_d $\frac{gm\ C}{m^2 \cdot d}$	GPP_d $\frac{gm\ C}{m^2 \cdot d}$
	Rhizophora[b]						
Dec. 5	shade lvs.	373	3.879	0.486	3.393	0.873	4.267
" 5	sun lvs.	304	4.530	0.541	3.990	0.972	4.962
" 5	proproot	NA	NA	NA	NA	0.592	NA
" 5	trunk	NA	NA	NA	NA	1.049	NA
	Conocarpus[c]						
" 5	sun lvs.	353	4.035	0.691	3.344	1.243	4.587
" 5	shade lvs.	400	3.352	0.717	2.634	1.290	3.924
" 7	shade lvs.	390	3.774	0.589	3.184	1.059	4.244
	Avicennia[d]						
" 8	sun lvs.	360	1.179	0.317	2.136	0.570	2.707
" 8	shade lvs.	360	0.859	0.238	0.621	0.429	1.049
" 8	trunk	NA	NA	NA	NA	1.919	NA

a NPP = net primary production
R = respiration
GPP = gross primary production
Lp = photoperiod
Dp = Dark period (13.4 hours)
d = 24 hour day

b red mangrove
c buttonwood
d black mangrove

Table XII-10. Diurnal metabolic rates for various components of a mangrove forest community associated with the upper reaches of the Fahka Union River, Station D, 1972.

Plant Type	Plant Component	Metabolism[a] gm C/m^2/day GPP_{24}	 NPP_{24}	 R_{24}
Red mangrove	Shade lvs.	3.43	2.56	0.873
	Sun lvs.	4.80	3.82	0.972
	Proproot	NA	NA	0.592
	Trunk	NA	NA	1.05
Black mangrove	Shade lvs.	0.890	0.461	0.429
	Sun lvs.	1.21	0.643	0.570
	Trunk	NA	NA	1.92
Buttonwood	Shade lvs.	3.17	2.00	1.17
	Sun lvs.	3.90	2.66	1.24

[a] Productivity based on average daily solar radiation of 293 langleys.

As indicated previously, species zonation was apparent at Station D. Red mangroves fronted the river's edge, and black mangroves dominated the interior zone with a scattering of mature buttonwood. The interior region was obviously subjected to only occasional tidal flushing. Extensive litter accumulation was in progress on the forest floor. The absence of black mangrove pneumatophores indicated the zone was well drained. The presence of black mangrove pneumatophores is usually associated with poorly drained soils. Pneumataphores have been recognized as special adaptational structures for a gas exchange mechanism in which oxygen is transported to the root assemblages (Scholander, et al., 1955). Species zonation would seem to be related to metabolism. The red mangroves maintained a gross productivity nearly four times that of the black mangroves under equal conditions of incoming solar radiation. Likewsie, the gross productivity of the buttonwood was less than that observed for the red mangroves. Lugo, et al. (in press) reported a similar scheme of mangrove zonation on a basis of species metabolism.

The next downstream site (Station E) selected for study was also subject to slight changes in chlorides, but at higher concentrations than Station D. Soil water chlorides varied from 10.9 ppt to 12.5 ppt and averaged 11.6 ppt over a 24-hour period. To establish a chloride relationship between surface and soil water, paired sampling was conducted two months later. At this time, chloride concentration of the soil water was 13.7 ppt vs 12.7 ppt for the surface waters. This site was subject to semidiurnal tidal flushing.

The assemblage of plant species representing the saltgrass marsh community at this station was markedly divergent from that of the upstream marsh station. The latter area was shared between several plant species, whereas at the downstream site only _Spartina spartina_ and _Distichlis spicata_ (commonly known as saltgrass) were found. The increase in chloride gradient from the upstream site to the present location may be the environmental factor dictating the difference in species composition. A marked increase in chloride levels (salinity) may pose a potential stress condition. Those species lacking the physiological machinery to cope with this new situation yield their position in the community to more suited populations. Hence the surviving populations may respond with added vigor to the diminished competition for space and nutrients.

Possibly this is the case for the two saltmarsh plant species reported above. Observed rates of photosynthesis and respiration are reported for the community in Table XII-11. These rates after normalization for differences in chamber biomass and incident solar radiation appear in Table XII-12.

Possibly coupled to the measured increase in Spartina and saltgrass productivity was an auxiliary nutrient source. A mussel population was found inhabiting the root masses of Spartina. Their presence was not noted at Station D. Odum (1971) cites the work of Kuenzler (1961, 1961a) and Pomeroy, et al. (1967) concerning mussel populations as biotic mechanisms for recycling phosphorus. The latter investigators demonstrated the role of mussels as auxiliary nutrient sources in a Spartina marsh in Georgia.

Table XII-11. Results from plant metabolic studies conducted to determine primary production of salt [illegible] plants and mangroves associated with the mid-reach of Fahka Union River, station E, 1972

Date (1972)	Vegetation	Chamber Bio[illegible]mposition gm/m^2 ([illegible]ree Wt.)				Total Solar Radiation ly/Lp	Plant Metabolism[a]				
		Total	Green Lvs.	Above Ground Dead	Roots		NPP_{Lp} gm C/m^2.Lp	R_{Dp} gm C/m^2.Dp	NPP_d gm C/m^2.d	R_d gm C/m^2.d	GPP_d gm C/m^2.d
Nov 17	Spartina	2,002.9	626.4	781.5	595.0	398	2.572	1.395	1.177	2.560	3.737
Nov 18	Spartina	2,002.9	626.4	781.5	595.0	320	2.038	1.554	0.484	2.852	3.336
Nov 17	Spartina	3,272.8	919.0	824.7	1,528.2	398	3.305	1.700	1.604	3.120	4.725
Nov 18	Spartina	3,272.8	919.0	824.7	1,528.2	297	2.253	1.736	0.517	3.185	3.703
Nov 17	Distichilis	3,284.8	951.9	481.3	1,851.6	392	4.273	2.015	2.258	3.697	5.712
Nov 18	Distichilis	3,284.8	951.9	481.3	1.851.6	360	5.194	2.066	3.127	3.791	6.919
Nov 17	Distichilis	3,846.5	1,725.8	730.1	1,390.6	392	4.221	2.799	1.422	5.135	6.557
Nov 18	Distichilis	3,846.5	1,725.8	730.1	1,390.6	360	5.008	2.366	2.642	4.342	6.984
	Rhizophora[c]										
Nov 21	sun lvs.	NA	NA	NA	NA	306	2.670	0.438	2.233	0.798	3.031
Nov 22	sun lvs.	NA	NA	NA	NA	75	1.095	0.454	0.641	0.829	1.469
	Laguncularia[d]										
Nov 22	sun lvs.	NA	NA	NA	NA	75	1.539	0.400	1.139	0.706	1.845

[a] NPP - net primary production
R - respiration
GPP - gross primary production
Lp - photoperiod
Dp - dark period (13.1 hours)
d - 24 hour day

[b] Saltgrass

[c] Red mangrove

[d] White mangrove

Table XII-12. Mean rates of productivity and respiration for plant species characteristic of the saltgrass marsh associated with the mid-reaches of the Fahka Union River, Station E, 1972.

	Mean Chamber Biomass, Ash Free Wt. (gm/m^2)				Metabolism (gm C/m^2/day)[a]		
Plant	Total	Green Lvs.	Above-Ground Dead	Roots	GPP_{24}	NPP_{24}	R_{24}
Distichlis sp.	2,637.8	772.7	803.1	1,061.6	5.07	0.847	4.22
Spartina sp.	3,565.6	1,338.8	605.7	1,621.1	3.52	0.474	3.05

[a] Rate normalized for biomass and light

By comparison, both species showed a marked increase in gross productivity over their counter-parts in the less saline marshes located upstream (Station D). These increases in total carbon budget (GPP) may be of some consequence to community structure.

For example, in the upstream marsh, approximately 89 percent of the carbon economy of Eleocharis sp. was diverted to maintenance of community respiration; a percentage derived from the ratio $\frac{R_{24}}{GPP}$. The percentages of the carbon budget devoted to maintenance by Spartina sp. and Distichlis sp. were 79 and 67 percent, respectively.

In contrast, where fresh water was less available for metabolism, the plants perhaps rely to a greater degree on their physiological machinery to cope with the added environmental stress. The added metabolic "strain" might place additional drains on the plant's carbon budget. In the case of Eleocharis sp., it appears that the added cost for survival on its carbon economy was overwhelming, hence, the population dropped from the community at Station E. On the other hand, Spartina sp. and Distichlis sp. maintained their position in the community by increasing their gross carbon budget to meet the additional constraints of respiration, which in this case were 87 and 83 percent of gross production, respectively. This increase in gross productivity correlates with a diminished competition for space and nutrients.

Assessment of mangrove metabolism was limited to an immature red and white mangrove community, which fronted the edge of the river channel. Observed rates of metabolism are reported in Table XII-11.

After normalizing the measured net productivity rates for equal solar radiation, major differences in their gross metabolism of carbon can be seen in Table XII-13.

The structure of the white mangrove population at Station E may account for the high net productivity reported. Although most of the individual trees maintained a canopy height similar to the reds, their overall structure indicated an immature population. Lateral branching began near ground level, and the upper

Table XII-13. Diurnal productivity rates of sun leaves for red and white mangrove inhabiting the stream side of the mid-reach of the Fahka Union River, Station E, 1972.

Plant	Metabolism[a] gm C/m^2/day		
	GPP_{24}	NPP_{24}	R_{24}
Red mangrove	3.79	2.97	0.817
White mangrove	6.32	5.61	0.706

a Productivity based on average daily solar radiation of 293 langleys.

story canopy was not a crown-like feature typical of more mature populations. High net productivity and low expenditures of energy for respiration might be consonant with work processes directed at a rapid accumulation of biomass.

The lower Fahka Union River site (Station F) represented a position in the drainage basin of less freshwater availability. This is substantiated by the following reported chloride concentrations.

Chloride concentrations of the river water at this site averaged 12.7 ppt and ranged from 8.2 ppt to 17.0 ppt over a 24-hour period. The relative wide range in chloride level reflects the presence of fresh water from the Fahka Union Canal backing up into the lower reach of the river during flooding tide. Paired analyses of soil solution and surface water chloride yielded a concentration of 18.4 and 16.2 ppt. These analyses were conducted approximately two weeks after the start of the metabolic studies at this location. Species zonation was apparent. As before, red mangroves lined the shore of the river. Black and white mangroves coexisted in the interior zone with a few scattered individual reds. Some black mangrove pneumatophores were present on the forest floor of the interior zone, but their numbers were relatively few with respect to the profuse numbers usually found in the poorly flushed black mangrove forests. Results of the metabolic measurements are reported in Table XII-14. Productivity rates adjusted for equal light conditions are given in Table XII-15. From Table XII-15, species zonation on the basis of metabolism was indicated.

Station G represented the estuarine position in the freshwater gradient line established for the study of mangrove metabolism. At this site, bay water flooded the land area on a semidiurnal frequency. Immediate effects of this tidal flushing were evident. The forest floor was virtually swept clean of debris. At the time of study, the measured chloride content of the flooding water averaged 16 ppt and ranged from 15.0 to 17.0 ppt over a 24-hour period. Subsequent paired samples of soil solution and surface water were obtained and analyzed for chloride content. Concentration of chlorides were 18.2 and 18.0 ppt, respectively.

The mangrove forest maintained a scheme of species zonation similar to the other study sites. Red mangroves were predominant along the edge of the stream while black and white mangroves were representative of the interior zone. Measured metabolic rates for this community are given in Table XII-16. To render

Table XII-14. Results from plant metabolic studies conducted to determine primary production of mangroves associated with the lower Fahka Union River Basin, Station F, 1972.

			Plant Metabolism[a]				
Date (1972)	Vegetation	Total Solar Radiation ly/Lp	NPP_{Lp} $\frac{gm\ C}{m^2 \cdot Lp}$	R_{Dp} $\frac{gm\ C}{m^2 \cdot Dp}$	NPP_d $\frac{gm\ C}{m^2 \cdot d}$	R_d $\frac{gm\ C}{m^2 \cdot d}$	GPP_d $\frac{gm\ C}{m^2 \cdot d}$
	Rhizophora[b]						
Dec. 14	sun lvs.	213	1.958	0.149	1.808	0.265	2.074
" 15	trunk	NA	NA	NA	NA	0.406	NA
" 15	proproot	NA	NA	NA	NA	0.747	NA
	Avicennia[c]						
" 14	sun lvs.	213	1.523	0.140	1.383	0.250	1.632
" 15	trunk	NA	NA	NA	NA	0.323	NA
	Laguncularia[d]						
" 14	sun lvs.	240	1.277	0.126	1.151	0.225	1.376
" 15	trunk	NA	NA	NA	NA	0.126	NA

a NPP = net primary production
R = respiration
GPP = gross primary production
Lp = photoperiod
Dp = dark period (13.5 hours)
d = 24 hour day

b Red mangrove
c Black mangrove
d White mangrove

Table XII-15. Diurnal metabolic rates for various components of the mangrove forest community associated with the lower reach of the Fahka Union River, Station F, 1972.

		Metabolism[a] gm C/m^2/day		
Plant	Components	GPP_{24}	NPP_{24}	R_{24}
Red mangrove	Sun lvs.	2.81	2.54	0.265
	Trunk	NA	NA	0.406
	Proproot	NA	NA	0.747
Black mangrove	Sun lvs.	2.20	1.96	0.250
	Trunk	NA	NA	0.323
White mangrove	Sun lvs.	1.66	1.43	0.225
	Trunk	NA	NA	0.126

a Productivity based on average daily solar radiation of 293 langleys.

Table XII-16. Summary of results from plant metabolic studies conducted to determine primary productivity of mangroves associated with a small tidal stream of Fahkahatchee Bay, Station G, 1972.

Date 1972	Vegetation	Total Solar Radiation ly/L_p	Metabolism[a]				
			NPP_{Lp} $\frac{\text{gm C}}{m^2 \cdot L_p}$	R_{Dp} $\frac{\text{gm C}}{m^2 \cdot D_p}$	NPP_d $\frac{\text{gm C}}{m^2 \cdot d}$	R_d $\frac{\text{gm C}}{m^2 \cdot d}$	GPP_d $\frac{\text{gm C}}{m^2 \cdot d}$
	Rhizophora[b]						
Dec. 20	Sun lvs.	248	0.719	0.263	0.350	0.469	0.818
Dec. 21	Sun lvs.	173	0.596	0.274	0.322	0.496	0.809
Dec. 19	Trunk	NA	NA	0.315	NA	0.559	NA
Dec. 19	Proproot	NA	NA	0.493	NA	0.876	NA
	Avicennia[c]						
Dec. 20	Sun lvs.	248	2.35	0.782	1.57	1.39	2.96
Dec. 21	Sun lvs.	183	1.11	0.568	0.538	1.01	1.55
Dec. 20	Trunk	NA	NA	0.630	NA	1.12	NA
	Laguncularia[d]						
Dec. 20	Sun lvs.	275	2.55	0.918	1.64	1.63	3.27
Dec. 21	Sun lvs.	191	0.813	ND	NA	NA	NA
Dec. 19	Trunk	NA	NA	1.16	NA	2.07	NA

a Productivity based on average daily light of 293 langleys.
b Red mangrove
c Black mangrove
d White mangrove

the observed production rates of each species more comparable, net production was normalized for equal light. The adjusted data is given in Table XII-17.

Discussion

For the purpose of the study, the freshwater gradient as assessed by chloride concentration was established along a north to south line. Starting at Station E, the northernmost point on the gradient, surface water chlorides averaged 4.7 ppt. Chloride levels for both soil and surface waters steadily increased at successive downstream sites with a maximum observed concentration of 18 ppt occurring at Fahkahatchee Bay (Station G).

Mangrove metabolism responded to the freshwater gradient in two directions. First, a lateral zonation by species was evident on the basis of leaf gross productivity and tidal flushing. Secondly, a near linear response in species metabolism occurred with decreasing availability of fresh water.

Table XII-17. Diurnal metabolic rates for various components of the mainland mangrove forest community associated with a small tidal stream in Fahkahatchee Bay, Station G, 1972.

Plant	Components	Metabolism[a] gm C/m^2/day		
		GPP_{24}	NPP_{24}	R_{24}
Red mangrove	Sun lvs.	1.14	0.661	0.477
	Trunk	NA	NA	0.559
	Proproot	NA	NA	0.876
Black mangrove	Sun lvs.	2.80	1.60	1.20
	Trunk	NA	NA	1.12
White mangrove	Sun lvs.	3.43	1.80	1.63
	Trunk	NA	NA	2.07

a Mean diel productivity based on average daily light of 293 langleys.

A review of Tables XII-10 and 15 will indicate that leaf metabolism was greater for the red mangroves than for either the black or white species. In both cases, the reds were exposed to tidal dynamics more frequently than the other species, which occupied the interior zones of the community. At Station G, Fahkahatchee Bay, the three species appeared to be equally subjected to tidal flushing; however, the metabolic response by species was reversed (Table XII-16). Red mangrove production was secondary to both the black and white specimens. A similar species zonation scheme based on mangrove metabolism was reported by Lugo, et al. (In Press).

By species, the response of metabolism to decreasing freshwater concentration was evident in Table XII-17. The data reported have been converted to unit area of metabolic surface per unit land area. This procedure takes into account structural and density dissimilarities between and within species populations. To accomplish the land area conversion requires multiplication of the initial metabolic rates by the appropriate land area index (i.e., total leaf surface area per unit land area).

Indices for leaf area were obtained from the reported work of Snedaker, et al. (in press). These investigators studied the structural arrangement of different mangrove stands in the region of the present study. Their report included estimates of leaf area indices representative of codominant red-black and red-white mangrove stands. The forest stand yielded leaf area indices of 1.9 to 2.1, and 2.1 to 2.4, respectively. These indices were assumed to be appropriate for the mangrove stands at Stations D and E; however, Stations F and G were represented by a roughly codominate forest of red, black and white mangroves. For the purpose of this study, we took the average total of the leaf area indices for the two mangrove stands (4.2) reported by Snedaker, et al., and assumed it representative of the three-way mixed forest at Stations F and G. The average divided by three provided a crude estimate of leaf area index (1.4) for each species.

Indices for mangrove trunk and red mangrove proproot area were obtained from reported investigations by Lugo, et al. (in press). These investigators studied mangrove metabolism and structure of a three-way mixed forest at Rookery Bay, Naples, Florida.

It is evident that the gross productivity of mature red mangroves decreases with increasing salinity (Table XII-18). The opposite trend was true for mature black and white mangroves, in which gross metabolism increased with salinity. These production-salinity relationships are graphically shown in Figure XII-20. In the case of the white and red mangrove response, the GPP values reported for Station E were omitted from the figure. As indicated previously, the metabolic measurements were for immature trees not comparable structurally or metabolically to the mature individual trees studied. To view the response of community metabolism to changing conditions of fresh water only requires a summing of the species GPP rates by station, as reported in Table XII-18. Community metabolism is given in Table XII-19.

Table XII-18. Mangrove metabolism with respect to changes in chloride concentration, 1972. Metabolic values corrected for leaf, trunk, and proproot area indices.

Species	Station	Plant Metabolism (gm c/m^2/day)						Compartment Indices [a]		
		Mean Chloride (ppt)	Proproot	Trunk	Leaves		Species			
			R_{24}	R_{24}	R_{24}	NPP_{24}	GPP	Proproot	Trunk	Leaves
Red Mangrove	D	4.7	0.40	0.07	1.8	5.7	8.0	0.67	0.07	1.9
	E	11.6	ND	ND	1.7	6.3	8.0	0.67	0.07	2.1
	F	12.7	0.50	0.03	0.37	3.0	3.9	0.67	0.07	1.4
	G	16.0	0.59	0.04	0.67	0.25	1.6	0.67	0.07	1.4
Black Mangrove	D	4.7	NA	0.24	1.1	0.94	2.31	NA	0.07	2.1
	E	11.6	NA	ND	ND	ND	ND	NA	0.07	2.1
	F	12.7	NA	2.7	0.34	2.7	5.7	NA	0.07	1.4
	G	16.0	NA	3.6	1.7	2.2	7.5	NA	0.07	1.4
White Mangrove	D	4.7	NA	ND	ND	ND	ND	NA	0.07	1.4
	E	11.6	NA	ND	1.7	13.0	15.0	NA	0.07	2.4
	F	12.7	NA	0.08	0.36	1.8	2.2	NA	0.07	1.4
	G	16.0	NA	0.14	2.3	2.4	4.8	NA	0.07	1.4

[a] m^2 metabolic surface per m^2 land area

[b] representative of immature specimens

[c] calculated estimate

From Table XII-19 it is evident that the carbon budget (GPP) generated by the mangrove system grows larger as fresh water becomes less available. This appears to be a plus for the community. However, a closer examination of the situation reveals that increased respiration applies heavy pressures against the carbon economy of the system. This is apparent by comparing the percentage of the carbon budget devoted to respiration at Stations D, F and G. Respectively, respiration demands are 35.9, 36.9, and 65.5 percent of the total budget. This aspect of the data has already been discussed in terms of the salt marsh community. Some further discussion of mangrove community response is given in Chapter V.

UPLAND COMMUNITY BIOMASS AND METABOLISM

Biomass

Introduction

This section reports studies conducted to assess drainage effects on upland terrestrial plant communities of the Fahkahatchee Strand and associated areas. Study emphases were placed on the cypress and wet prairie communities. Of the two, only the former community was studied thoroughly enough to yield sufficient data on biomass to make comparisons between drained and undrained regions (Figure XII-21 areas A and B, respectively). Details of the plant taxonomic features of the areas are reported in Chapter XIII.

Methods

Two techniques were used to assess changes in community biomass. The least difficult of the two involved the herbaceous plants associated with the ground cover of the cypress strands and the wet prairies. In these areas, the plants, including roots in a 0.25 m^2 plot were harvested at selected points along a transect that measured 100 meters long and was sequentially numbered at one meter intervals. Sampling was with replication, usually four. Points of harvesting were selected from a book of random numbers.

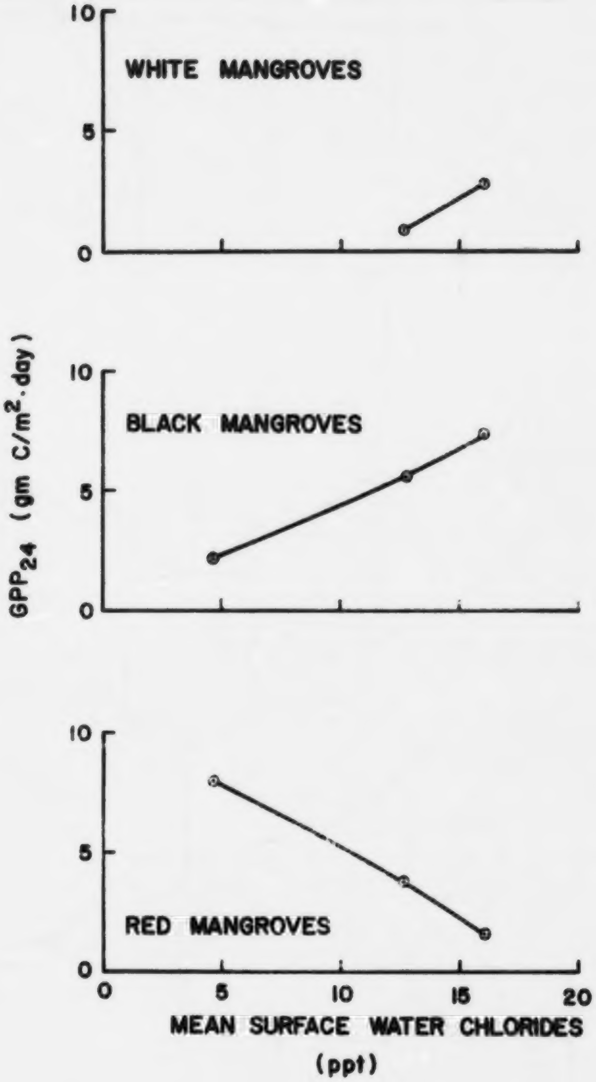
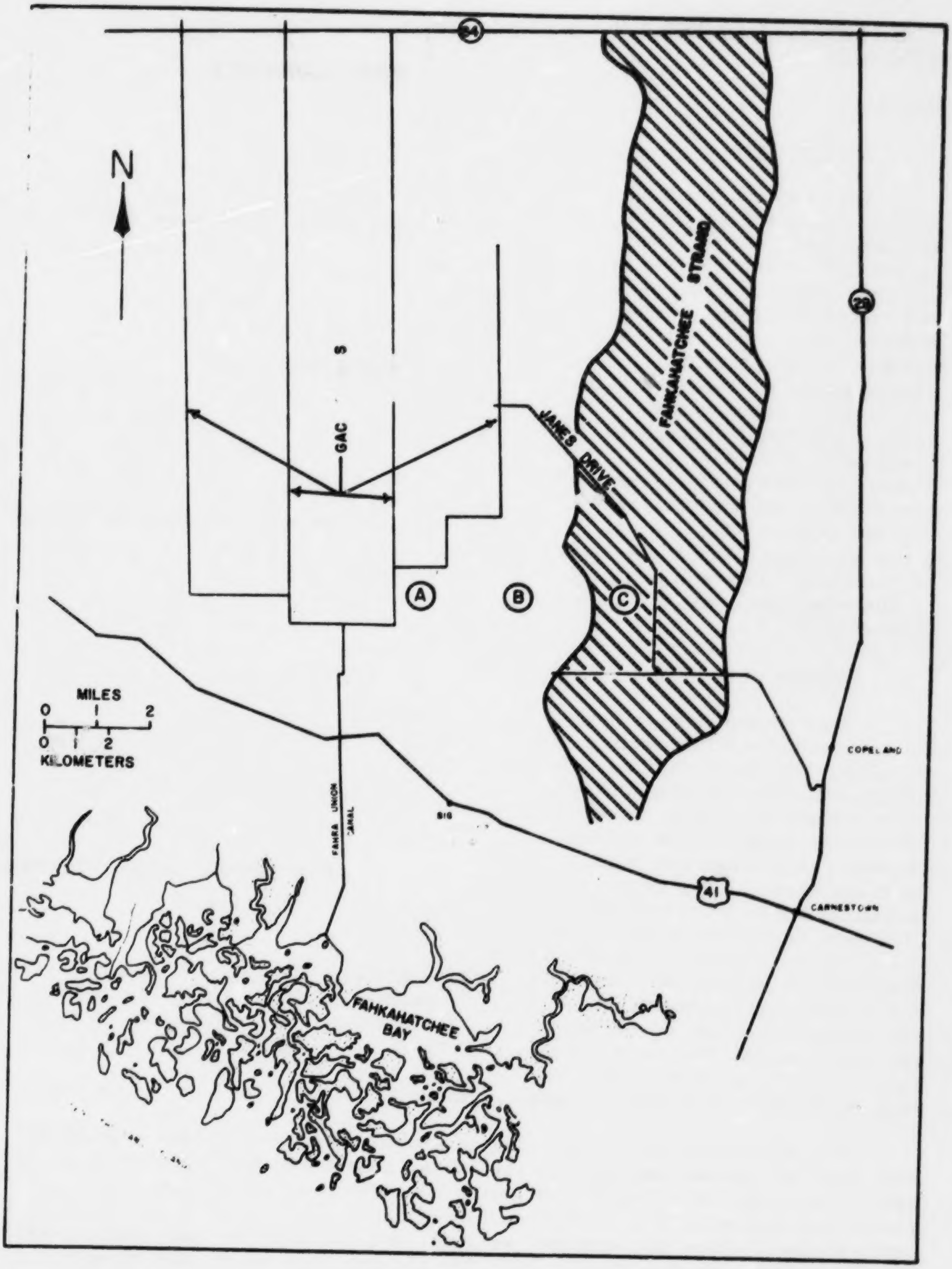


Figure XII-20. Response of mangrove gross primary productivity to decreasing concentration of fresh water. Nov.-Dec. 1972.

The harvesting method included separating the above ground vegetation into dead and green components. The roots, from a maximum depth of about 30 cm, were first separated from the soil with a coarse mesh sieve (6 mm mesh) and then washed and drained. All material was oven dried at 103 ± 2° C for three to four days, cooled to room temperature, weighed, and analyzed for ash-free dry weight. Biomass results are reported in both dry and ash-free weight per square meter of community.


84
N
GAC
S
JANES DRIVE
FAHKAHATCHEE STRAND
29
A
B
C
MILES
0 1 2
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KILOMETERS
COPELAND
FAHKA UNION CANAL
BIG
41
CARNESTOWN
FAHKAHATCHEE BAY

Figure XII-21. Location of sampling areas.

Table XII-19. Response of mangrove community metabolism to changing concentrations of chlorides (fresh water), 1973.

Station	Mean Surface Water Chlorides (ppt)	Community Metabolism (gm C/m^2/day)		
		GPP$_{24}$	NPP$_{24}$	R$_{24}$
D	4.7	10.3	6.6	3.7
F	12.7	11.8	7.5	4.3
G	16.0	13.9	4.8	9.1

Harvesting of large numbers of trees and shrubs to assess changes in community biomass was impractical. To save both time and landscape, several large quadrats (10 m X 10 m) were established in the two cypress strand areas (areas A and B, Figure XII-21). In each plot, all trees and shrubs were identified and their position in the plot marked by coordinates. Figure XII-22 gives an actual example of a surveyed quadrat in area B. Each specimen was

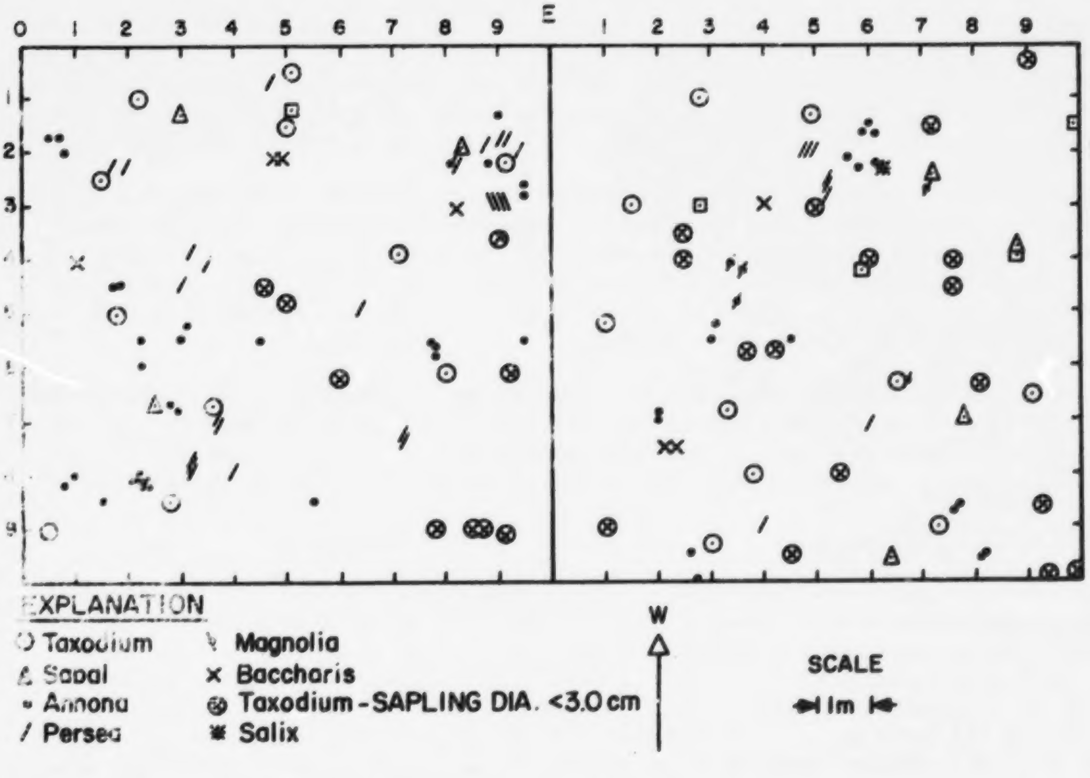
0 1 2 3 4 5 6 7 8 9
E
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
EXPLANATION
Taxodium
Sabal
Annona
Persea
Magnolia
Baccharis
Taxodium-SAPLING DIA. <3.0 cm
Salix
W
SCALE
1m

Figure XII-22. Example of a surveyed quadrat.

assigned an aluminum tag bearing physical dimensions of the plant, date of survey, and coordinate numbers. This tag served to identify the individual at a later date when the indicated dimensions were remeasured. Changes in biomass were determined from the before and after measurements. The relationship of selected physical dimensions to biomass was derived in the following manner.

Regression equations describing biomass as a function of selected physical dimensions were established specifically for this study. Data for the regression analysis were obtained by measuring, harvesting and weighing different sized individuals of a given tree or shrub.

First, tree trunk diameters were measured at a point of 137 cm above ground with a DBH meter (Diameter at Breast Height). To measure small diameters (< two cm) a caliper was used. In the case of shrubs or seedlings, trunk diameters were measured at a point of 20 cm above ground.

After the tree or shrub was cut down with a chain or hand saw, the total height of the plant was measured. Then the leaves and woody components were separated. The woody parts were separated further into twigs (< one cm in diameter) which included leaf buds and stems, limbs, and trunk. All vegetative fractions were weighed for fresh weights and subsampled for dry weight conversion and chemical analyses. Fresh weights were obtained in the field with the use of a 22 and 2.6 kilogram capacity triple beam balances.

Calculation of the regression equations and correlation coefficients was accomplished with a statistical programmable calculator. The calculator programs test various regression forms (linear, exponential, or parabolic) using various physical dimensions (diameter, height, diameter times height or diameter squared times height). Data used in the regression analyses are given in Appendix S.

The power curve relationship of biomass vs square root of diameters multiplied by height was found to yield the highest correlation value of the different regression models tested (Appendices T, U, and V). Only the Sabal palmetto (cabbage palm) failed to conform well to the $(D \cdot H)^{0.5}$ regressions. One might expect the palm, with its columnar growth, not to conform with the regression patterns of dicots and conifers.

Generally, the woody and leafy biomass regression equations show correlation coefficients well above 0.9. The exceptions were leafy biomass regressions for a few deciduous tree species. Since the deciduous species were sampled in the late fall, this is not unexpected because of possible differences in leaf-fall.

Results and Discussion

Dramatic differences in standing crop between the drained and undrained cypress strand areas were evident. The drained area (area A, Figure XII-21) was consistently lower in biomass and showed an average standing crop of woody plants of 8,935.5 grams dry wt/m^2 (from March 15, 1972 to January 16, 1973) compared to the undrained area (area B, Figure XII-21) of 17,120.2 grams dry wt/m^2 during the same period. Comparison of the growth of biomass was equally impressive. The drained area of woody plant biomass increased by 119.6 grams/m^2 during the 307 day period. The undrained area yielded a biomass increase of 485.0 gm/m^2 during a 302 day period (Table XII-20). This annual increase translates into rates of 0.390 gm/m^2·day and 1.606 gm/m^2·day, respectively. The undrained site had a rate of increase in biomass over four times that of the drained area.

Table XII-20. Community stand table for woody plant biomass (wood and leaf masses) in an undrained and drained area of a cypress strand.

Undrained Area

Genus	Mean Biomass gm/m^2	Change in Biomass gm/m^2
Taxodium	15,790.3	81.995
Myrica	262.4	106.599
Baccharis	11.6	5.164
Sabal	890.7	252.029
Annona	8.1	0.327
Magnolia	8.6	2.506
Salix	2.0	0.187
Persea	146.8	36.339
Total	17,120.2	485.0[a]

a For 302 days = 1.606 gm/day.

Drained Area

Genus	Mean Biomass gm/m^2	Change in Biomass gm/m^2
Taxodium	8,167.6	44.106
Myrica	613.7	73.482
Salix	100.2	-2.773
Cephalanthus	42.5	-0.405
Persea	10.3	3.36
Fraxinus	0.2	0.005
Acer	1.1	0.245
Total	8,935.5	119.6[b]

b For 307 days = 0.390 gm/day.

The herbaceous ground cover plants of the cypress strands followed a similar trend (Figure XII-23). The average standing crop of herbs in the drained area was 1,153.5 gm/m^2 from January 31, 1972 to October 12, 1972 compared to 1,945.3 gm/m^2 in the undrained area (from February 11, 1972 to September 9, 1972). The change in biomass in the drained area was -20.0 gm/m^2 for the 255 day period compared with +311.6 gm/m^2 for the 211 day period in the undrained area. This is a rate of -0.078 gm/day and 1.477 gm/day, respectively.

Combining the woody plants with the herbaceous plants the net gain in biomass becomes 0.312 gm dry wt/day in the drained area and 3.083 gm dry wt/day in the undrained area. The net increase in biomass was 10 times greater in the undrained cypress strand than the drained cypress strand.

A wet prairie in the drained region of study area (area A, Figure XII-21) was sampled for estimates of standing crop biomass on four occasions during the period of January 31 to October 5, 1972. Two wet prairies remote to canal drainage were sampled in area B (Figure XII-21) during the period February 11 to August 9, 1972. Results from sampling are presented in Table XII-21. Prairie fires in area B nullified any reasonable judgements concerning changes in standing crop biomass and differences in biomasses between drained and undrained prairies.

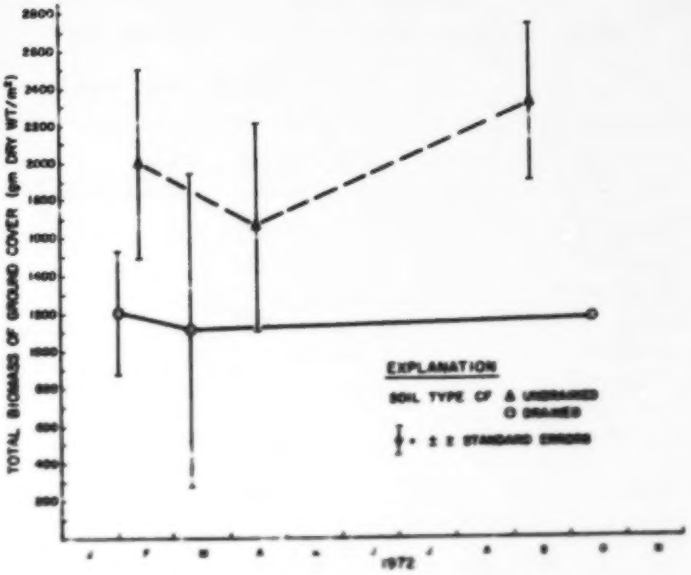

Figure XII-23. Average standing crop biomass of herbs in drained (area A, Figure XII-21) and undrained (area B, Figure XII-21) cypress strands, 1972.

Table XII-21. Average standing crop biomass with 95 percent confidence limits for wet prairies near (area A) and remote (area B) to a drainage canal, 1972.

Date 1972	Study Area	Soil Type	Biomass, Ash Free Wt. (gm/m²) Lvs.	Duff	Roots	Total
Jan. 31	A	Oe	154.1 ± 59.7	301.2 ± 37.6	461.5 ± 143.9	916.8 ± 177.3
Mar. 10	"	"	101.6 ± 41.7	284.0 ± 80.7	513.8 ± 168.0	899.4 ± 194.3
June 12	"	"	151.7 ± 62.3	368.8 ± 170.4	412.2 ± 128.7	932.7 ± 237.6
Oct. 5	"	"	308.2 ± 343.7	293.2 ± 510.6	608.8 ± 262.7	1,210.2 ± 1,105.3
Feb. 11	B	"	87.0 ± 38.8	500.4 ± 183.4	517.0 ± 178.7	1,104.5 ± 256.2
Apr. 14	"	"	63.7 ± 25.8	430.7 ± 167.7	461.1 ± 111.0	955.4 ± 257.8
Aug. 2	"	"	259.6 ± 58.6	620.6 ± 148.1	653.7 ± 106.4	1,533.9 ± 289.7
Aug. 7[a]	"	"	234.6 ± 234.9	46.0 ± 73.2	616.4 ± 188.7	897.0 ± 496.8
Feb. 16	"	Od	122.1 ± 30.5	296.2 ± 119.6	428.6 ± 86.9	843.2 ± 291.7
Apr. 14	"	"	93.0 ± 36.3	426.2 ± 163.4	453.3 ± 165.6	972.4 ± 328.3
Aug. 14[a]	"	"	458.4 ± 533.6	104.4 ± 22.2	871.1 ± 923.7	1,334.0 ± 1,435.1
Apr. 17[b]	"	"	29.0 ± 5.6	40.4 ± 10.6	781.6 ± 172.4	850.9 ± 172.9
Aug. 9	"	"	229.3 ± 45.7	139.8 ± 129.1	1,064.7 ± 250.0	1,433.8 ± 302.5

[a] Prairie burned April 20, 1972
[b] " " March 21, "

Litterfall in Woodlands

Introduction

Litterfall represents the fraction of plant net production which is not grazed, remineralized through decomposition, and accumulated as biomass. In stable mature woodlands much of the woody plants biomass ultimately becomes litterfall which enters into a detritus food chain (Odum, E. P., 1969).

Because litterfall is a function of net production in woodlands, it becomes a basis for assessing the effects of land drainage on woodlands. Litterfall is an important part of energy and nutrient budget for woodland ecosystems; a subject considered in Chapter II (Discussion and Conclusions). This section reports the results of litterfall studies in the various woodland communities of the study area. These woodlands included a segment of the central Fahkahatchee Strand (Figure XII-21, area C), a cypress strand remote to canal drainage (Figure XII-21, area B) and a cypress strand near a drainage canal (Figure XII-21, area A). For purposes of this study, areas B and C are referred to as undrained and area A as drained.

Methods

Collections of litterfall were with catch baskets measuring either one meter square or 0.25 m^2. Six of the latter units were used in the central strand and 18 to 20 of the smaller baskets were placed in each of the cypress strands. The m^2 baskets were shallow trays of fiberglass screening over a galvanized hardware cloth molded with six-inch sides. The smaller baskets were wooden frames of 3/4" x 2" firring strips with fiberglass screen bottoms. Mesh size of the screening was approximately 1.5 by 1.5 mm. The baskets were placed above the ground (to reduce moisture and decomposition of the litter) at regular intervals. Litter was collected periodically, separated, dried and weighed. Subsamples of the separate components, leafy, woody and fine (small or fragmented particles), were analyzed for organic nitrogen and phosphorus content and ash free dry weight. Litterfall rates reported were corrected for decompositional losses during periods between collection times (see the following section on decomposition.

Results

The following litter accumulation graphs (Figures XII-24 through 26) present the litter accumulation in the wooded communities. Tables XII-22, 23 and 24 give average daily litterfall based on litter collected throughout the year and corrected for decomposition in the baskets.

Comparison of the woody sites indicates that the central strand produced the greatest amount of litter (756 $gm/m^2.yr$). This area was characterized by a dense canopy of vegetation, rich organic soil, remote to drainage canal, and a lengthy hydroperiod. The central strand was considered the most stable and mature woodland community studied for litterfall in this report.

The cypress strand areas were characterized by fewer trees and more herbaceous plants than the central area. The undrained cypress strand showed an annual average rate of litterfall of 374 $gm/m^2/yr$ compared to somewhat less than 267 $gm/m^2/yr$ in the drained area. The drained area also maintained less standing crop biomass and developed the least amount of community growth.

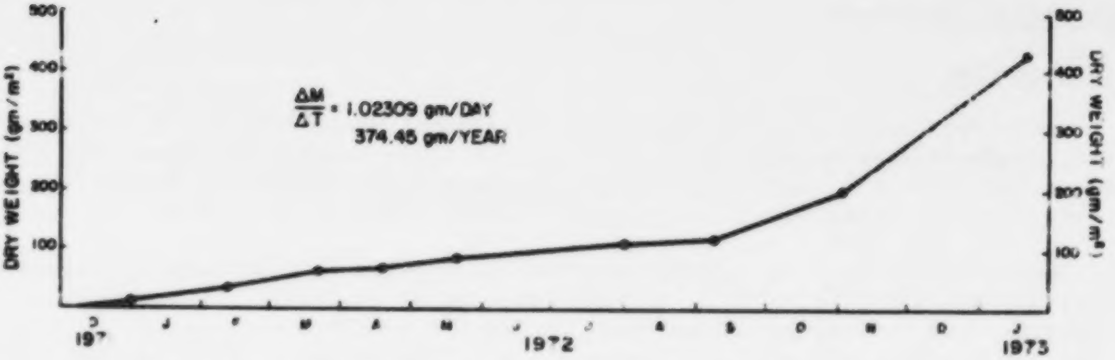

Figure XII-24. Litter accumulation in an undrained cypress strand (area B, Figure XII-21) 1971-73.

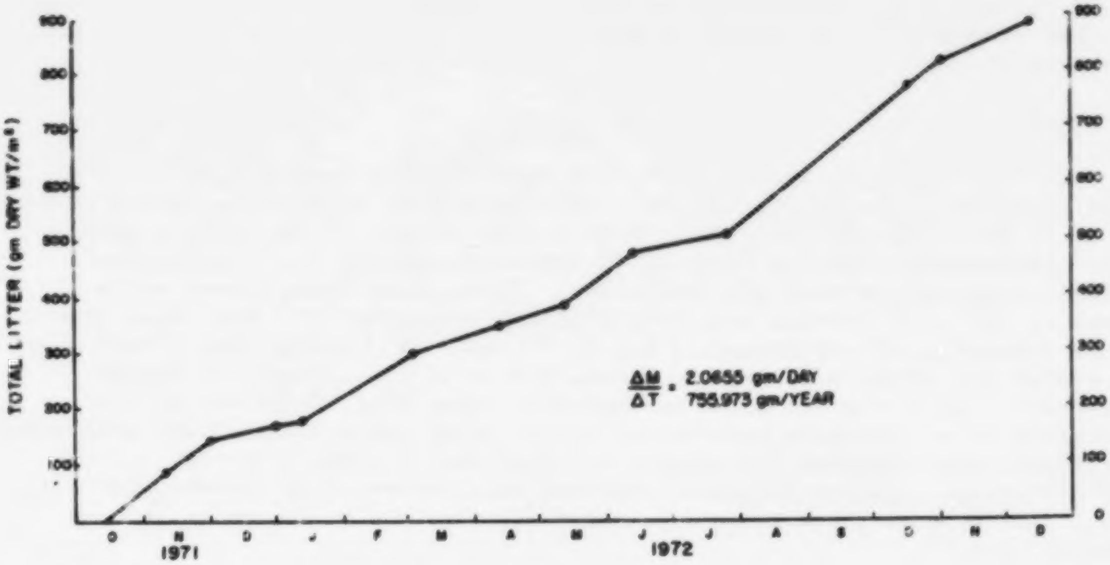

Figure XII-25. Litter accumulation in the central strand (area C, Figure XII-21), 1971-72.

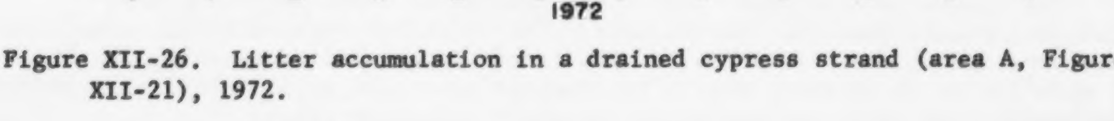

Figure XII-26. Litter accumulation in a drained cypress strand (area A, Figure XII-21), 1972.

Table XII-22. Litterfall in the central strand - undrained.

Collection Date	Period of Accumulation	Mean Litter Drop ($\bar{x} \pm \frac{2\sigma}{\sqrt{n}}$) Wood (gm/m^2 Dry Wt.)	(gm/m^2 Dry Wt.)	Mean Litter Drop: Corrected for Losses to Decomposition Subtended by Yield Per Day of Litter Wood (gm/m^2 Dry Wt.)	Leaves (gm/m^2 Dry Wt.)
Nov. 11, 1971	27	13.00 ± 18.44	68.78 ± 9.66	13.31 (0.49)	69.89 (2.59)
Dec. 3, 1971	22	8.45 ± 10.37	51.23 ± 11.96	8.96 (0.39)	51.90 (2.36)
Jan. 12, 1972	40	6.28 ± 4.82	29.98 ± 7.11	6.50 (0.16)	30.70 (0.77)
Mar. 3, 1972	51	71.13 ± 72.78	46.52 ± 17.02	74.33 (1.46)	47.95 (0.94)
Apr. 12, 1972	39	32.56 ± 58.15	16.18 ± 6.40	33.68 (0.86)	16.56 (0.42)
May 12, 1972	31	5.62 ± 5.11	25.85 ± 7.54	5.77 (0.19)	26.33 (0.85)
June 12, 1972	30	60.78 ± 53.32	29.85 ± 9.56	62.38 (2.08)	30.39 (1.01)
July 26, 1972	45	9.37 ± 17.58	20.93 ± 17.06	9.74 (0.22)	21.50 (0.48)
Oct. 18, 1972	84	107.35 ± 196.52	144.48 ± 17.31	115.39 (1.37)	151.83 (1.81)
Nov. 2, 1972	15	4.02 ± 3.30	32.77 ± 10.78	4.07 (0.27)	33.06 (2.20)
Dec. 13, 1972	41	4.75 ± 6.31	57.63 ± 11.18	4.92 (0.12)	59.05 (1.44)
Total litterfall				755.97	
Mean yield per day				2.06	

Table XII-23. Litterfall in the cypress strand - drained.

Collection Date	Period of Accumulation	Mean Litter Drop ($\bar{x} \pm \frac{2\sigma}{\sqrt{n}}$) Wood (gm/m^2 Dry Wt.)	Leaf and (gm/m^2 Dry Wt.)	Mean Litter Drop: Corrected for Losses to Decomposition Subtended by Yield Per Day of Litter Wood (gm/m^2 Dry Wt.)	Leaves (gm/m^2 Dry Wt.)
Mar. 3, 1972	58	4.60 ± 5.04	49.84 ± 23.00	4.836 (0.083)	51.60 (0.89)
Apr. 10, 1972	38	0.84 ± 0.88	15.56 ± 10.44	0.868 (0.023)	15.92 (0.42)
May 12, 1972	32	0.96 ± 0.12	17.16 ± 6.92	0.987 (0.031)	17.48 (0.55)
June 12, 1972	31	2.24 ± 1.52	23.76 ± 8.60	2.301 (0.074)	24.20 (0.78)
Jan. 15, 1973	217	1.36 ± 0.16	136.36 ± 44.84	1.633 (0.008)	154.76 (0.71)
Total litterfall				267.28	
Mean yield per day				0.73	

Table XII-24. Litterfall in the cypress strand - undrained.

Collection Date	Period of Accumulation	Mean Litter Drop ($\bar{x} \pm \frac{2\sigma}{\sqrt{n}}$)		Mean Litter Drop: Corrected for Losses to Decomposition Subtended by Yield Per Day of Litter	
		Wood (gm/m^2 Dry Wt.)	Leaf and fine material (gm/m^2 Dry Wt.)	Wood (gm/m^2 Dry Wt.)	Leaves (gm/m^2 Dry Wt.)
Feb. 11, 1972	65	1.30 ± 4.28	29.90 ± 5.96	1.375 (0.021)	31.17 (0.48)
Mar. 21, 1972	39	3.40 ± 5.80	24.18 ± 15.06	3.516 (0.090)	24.75 (0.63)
Apr. 18, 1972	28	0.22 ± 0.20	5.32 ± 2.45	0.225 (0.008)	5.41 (0.19)
May 20, 1972	32	0.44 ± 0.56	14.66 ± 9.34	0.452 (0.014)	14.94 (0.47)
July 31, 1972	72	12.16 ± 15.05	12.18 ± 5.79	12.938 (0.180)	12.71 (0.18)
Sept. 8, 1972	39	0.53 ± 0.59	8.44 ± 4.02	0.548 (0.014)	8.64 (0.22)
Nov. 2, 1972	55	1.12 ± 1.23	78.40 ± 16.44	1.174 (0.021)	81.00 (1.47)
Jan. 17, 1973	76	29.26 ± 54.46	177.16 ± 42.69	31.238 (0.411)	185.30 (2.44)
Total litterfall Mean yield per day				374.45 1.02	

Discussion

It is difficult to make a judgement about a plant productivity based on litterfall unless something is known about community structure. Based on results of the biomass studies of cypress strands, it is logical to assume that the drained area with its lower biomass, lower community growth and lower leaffall than the undrained area is in a reduced state of activity.

The turnover rate of leaf litterfall was greater in the drained cypress than in the undrained even though the absolute amount was less. The turnover rate of leaves for the undrained was 0.791 turnover per year. This value was arrived at by dividing leaffall per year (364 gm/m^2) by community mean leaf mass (460 gm/m^2). In the drained area the leaf turnover rate was 1.035 turnovers per year. This value was generated in the same manner given above. The 45 percent increase in turnover rate in the drained area may be due to stress from drainage resulting in a process of canopy thinning.

Decomposition of Litter

Introduction

Decomposition is an important process necessary in the cycling of minerals and nutrients. The rate of decomposition of litter in a given community determines the amount of carbon, nitrogen, phosphorus, and other minerals and nutrients that are tied-up in the litter component of a system and not available for converting to living protoplasm. Generally, high rates of remineralization accompany high productivity unless the decomposition attacks a substantial part of living matter. Enhancing the cycling of nutrients by rapid decomposition of litter speeds along productivity process.

This section reports decomposition rates of litter accumulations in the central strand, comparing microclimatic conditions on the strand floor and the dry elevated debris piles. The conditions on these elevated debris piles resembled those on the floor of dry or drained strands. In the latter situation there was a build-up of poorly decomposed litter and a reduction of humus, as compared with the central strand floor (Chapter XIII).

Methods

Decomposition was measured by setting out bags containing known quantities of litter and collecting sets of bags periodically. The initial litter used was collected at the same time from litter baskets. The initial litter was subsampled for analyses of organic nitrogen and phosphorus, dry weight, and ash free dry weight, and then separated on the basis of component (leaves, wood, and fine litter). Each component was divided equally by weight among 12 bags. The bags were of two types: six with 1/32 inch mesh size (fine mesh), and six with 1/16 inch mesh (coarse mesh). All bags were the 12 x 12 inch size with delta style knit from a commercial fisherman supply house that sold the items as "bait bags". A total of 24 bags were prepared: 12 were placed on the strand floor and 12 on debris piles. Both sets contained six coarse mesh bags and six fine mesh bags. This number of bags allows sampling of a fine and coarse mesh bag for both sites every two months for one year. The quantity (Q) of litter remaining in the bags at collection time is assumed to follow an exponential relationship with time (t): $Q = ae^{bt}$ (Figures XII-27 through 30 and Appendices W, X, Y and Z). This relationship assumes that decay is dependent on quantity. Decay equals quantity present times a constant. It follows that litter falling into the litter baskets (J) is related to time (t), quantity present (Qt) and the decomposition coefficient ($k = -b$) according to the equation $J = (Qtk)/\overline{1-e^{-kt}}$, if the quantity at time zero is zero and the litter falls at a steady rate. The decomposition coefficient equals -b in the equation $Q=ae^{-bt}$ describing the quantity of litter in a debris pile decay bag after a length of time.

Results

The decomposition rate on the strand floor was substantially higher than that on the debris piles. The coefficient of decomposition was 1.72×10^{-3} gm/gm·day dry weight for leaves on the strand floor compared to 1.33×10^{-3} gm/gm·day on the debris pile, both in fine mesh bags. For the coarse mesh bags, the difference was even greater; 2.69×10^{-3} gm/gm·day on the strand floor and 1.049×10^{-3} gm/gm·day on the debris pile (Table XII-25). Processes of remineralization as shown leads to a reduction in carbon content of litter; however, these processes result in a build-up of organic nitrogen. This is evident in Figure II-15.

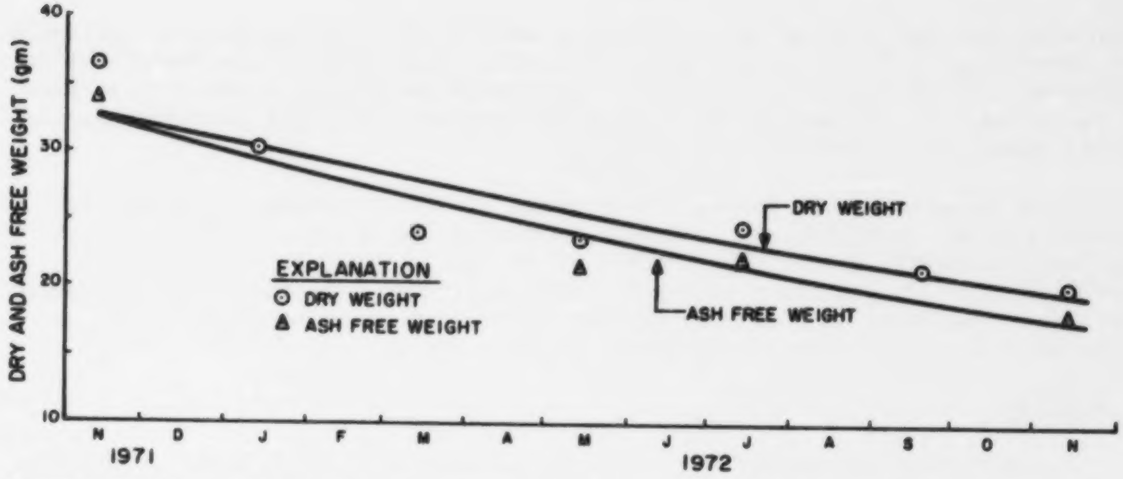

Figure XII-27. Litter decomposition on central strand floor, fine mesh. Figures based on data given in Table XII-34, 1972.

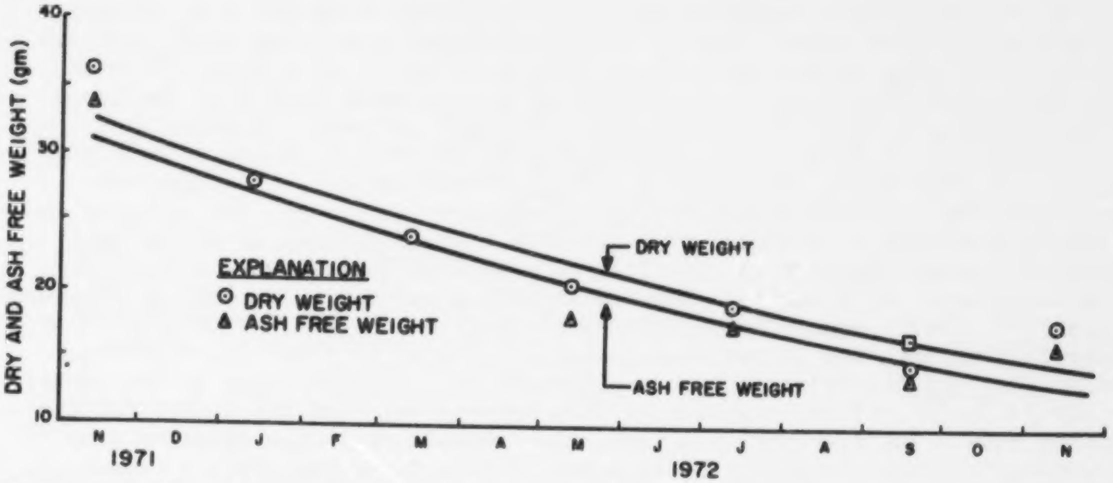

Figure XII-28. Litter decomposition on central strand floor, coarse mesh. Figure based on data given in Table XII-35, 1972.

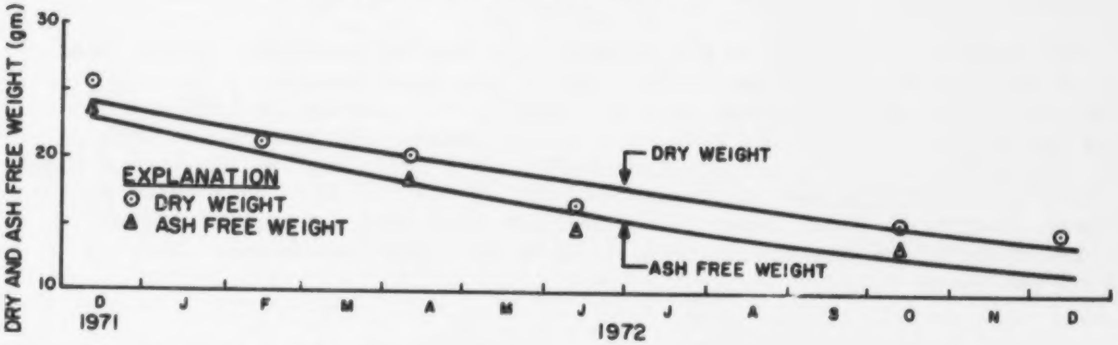

Figure XII-29. Litter decomposition on debris pile in central strand, fine mesh. Figure based on data given in Table XII-36, 1972.

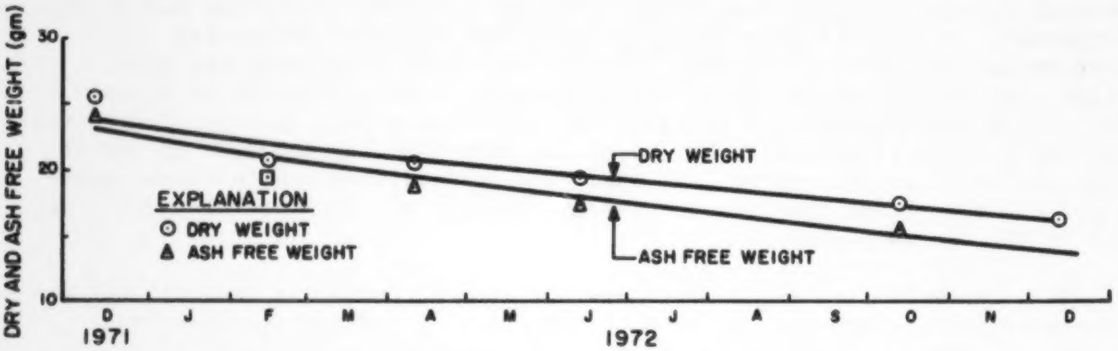

Figure XII-30. Litter decomposition on debris piles in central strand, coarse mesh. Figure based on data given in Table XII-37, 1972.

Table XII-25. Turnover rates of litter components, from least squares regression of data from decomposition materials. Units are in 10^{-3} (turnovers/day).

Litter Decay Bags	Wet			Dry		
	Total	Leaf & Fine	Wood	Total	Leaf & Fine	Wood
Coarse mesh						
Dry wt.	2.1309[a]	2.6860[a]	1.3098[a]	1.0637[a]	1.0492[a]	1.1408[a]
Ash-free wt.	2.2799[b]	2.9839[b]	1.2581[a]	1.4037[b]	1.3528[c]	-
Fine mesh						
Dry wt.	1.3391[a]	1.7227[a]	0.5877[c]	1.4542[a]	1.3338[a]	2.3412[a]
Ash-free wt.	1.6047[b]	2.0580[b]	0.5490[c]	1.8309[b]	2.3154[b]	2.9524[b]

Combined data (coarse & fine mesh bags) for debris pile (dry) litter bags

	Total	Leaf & fine	Wood
Dry wt.	1.259[a]	1.192[a]	1.741[a]
Ash-free dry wt.	1.618[a]	1.989[a]	2.318[a]

a Significant at 1% level.
b Significant at 5% level.
c Not significant at 5% level.

Discussion

Litter decomposition on the strand floor generally progressed at a greater rate than litter placed on the debris pile. This was probably due to increased activity of bacteria and detrital feeding organisms. The strand floor bags contained numerous limpits, amphipods, and even a sizeable crayfish during the hydroperiod. The debris pile bags also contained a number of species of invertebrates who were mainly small insects but their total mass was much smaller than that found in the strand floor bags. One collection of strand floor litter bags contained 0.07 gm in the coarse mesh bag. A later collection contained 0.15 gm invertebrate dry wt in the fine mesh bag and 0.25 gm dry wt of invertebrates in the coarse mesh bag. The large difference in faunal mass between the coarse and fine mesh bags helps explain why decomposition was more rapid in the coarse mesh.

This decomposition experiment does not take into account seasonal effects on remineralization because the initial litter collected for the study was obtained at only one point of the season. A comprehensive study of litter decay should examine the decomposition of litter collected at every season. The information gained in this study, however, does establish that microclimatic conditions associated with inundation effects remineralization.

TERRESTRIAL COMMUNITY METABOLISM

Introduction

Wet prairie communities constitute the second largest areal representation in the study area (Figure V-5a). This, coupled with ecotonal involvement of the grassy understory of cypress strands makes the wet grasslands, on a basis of land coverage, the principal plant community of the Big Cypress Swamp (Figure V-5b). Fortunately, these areas were considered ideal for metabolic studies since segments of the community could be readily isolated in metabolic chambers for field investigation.

Field studies were conducted to assess community primary productivity and evapotranspiration. The objective of these investigations was to relate community metabolism to ground water availability. Thus, study sites were established in prairie regions both near and remote to drainage canals.

Methods

Measurements of wet prairie community metabolism were accomplished in the same general manner previously described for the saltgrass marshes. Details of the methodology and equipment applied are given as an appendix to this chapter. An abbreviated version of the methodology and materials is reported in this section. In this case only the above ground portion of the wet prairie community was subjected to measurements of metabolic activity.

Open-ended chambers constructed of 6 mm diameter steel rod framing and covered with clear polyacetate (0.05 cm thick) were set over a segment of the prairie community and sealed to the ground. A fresh air supply to each chamber was regulated at a fixed rate that maintained a chamber overturn rate of five per minute. Temperatures within the chambers were usually less than 5^{0} C above ambient temperatures.

Community photosynthesis, respiration, and evapotranspiration were assessed on the basis of measured changes in the carbon dioxide and water vapor gradients across the chamber. Rates for community net primary productivity, respiration, and evapotranspiration are reported as totals derived from trapezodial integration of hourly rates and in terms of a per unit land area of the community.

Results

Field studies of wet prairie metabolism were conducted in June and October, 1972, at prairie site "A" and in August, 1972, at site "B". As indicated in the study of terrestrial biomass, Figure XII-21, the former area represented a region of the swamp adjacent to a major drainage canal and the latter area was a relatively undrained region. Results of the measurements of prairie activity are presented in Table XII-26.

Table XII-26. Results of studies to measure wet prairie community productivity, respiration, and evapotranspiration in areas near (area A) and remote (area B) to drainage canals. 1972.

			Chamber Biomass, Ash Free Wt. (gm/m^2)				Photo-Period	Light	Community Metabolism[a]			PE[c]
Site[b] Area	Date 1972	Soil Type	Green (lvs.)	Duff	Roots	Total	(hrs.)	(ly/day)	NPP_{Lp} gm C/m^2	R_{Dp} gm C/m^2	ET mm $H_2O/m^2/day$	mm $H_2O/m^2/day$
A	June 12	Oe	178.2	290.5	429.5	822.7	13.7	547	6.22	4.31	3.92	6.00
"	" "	"	128.3	397.7	453.2	979.2	"		5.33	4.26	4.63	6.00
"	Oct. 4	"	193.1	142.2	501.9	837.2	11.9	267	1.08	1.97	ND	
"	" "	"	269.8	210.1	610.9	1,090.8	"	"	2.97	0.97	"	"
"	" 5	"	193.1	142.2	501.9	837.2	"	426	1.20	1.14	1.68	3.90
"	" 6		269.8	210.1	610.9	1,090.8	"	248	3.11	1.27	4.29	6.38
B	Aug. 2	"	283.7	674.1	660.4	1,618.2	13.2	684	7.32	1.87	5.28	8.87
"	" "	"	258.6	631.3	692.8	1,582.7		"	8.86	1.12	3.57	
"	" 3	"	259.6	556.4	607.9	1,400.8	"	508	2.21	1.30	ND	ND
"	" 7[d]	"	216.1	40.3	601.5	857.9	"	453	9.00	4.37	8.24	8.51
B	" 9[e]	Od	230.5	199.6	1111.6	1,541.7	13.1	480	6.16	3.50	4.38	6.38
"	" "	"	247.0	105.6	949.2	1,301.8	"	"	6.05	3.29	4.51	
"	" "	"	400.4	102.7	943.8	1,446.9	13.0	453	9.18	4.44	7.00	"
"	" 14[d]	"	316.4	106.2	798.4	1,221.0	"	413	15.05	8.64	5.74	5.32

[a] NPP_{Lp} = net primary productivity during photoperiod.
R_{Dp} = respiration during darkness.
ET = evapotranspiration for 24 hours

[b] Area A = drained region
Area B = undrained region

[c] PE = pan evaporation at Big Cypress Bend.

[d] Prairie burned April 20, 1972.

[e] Prairie burned March 21, 1972.

To expand the reported activity rates into estimates of mean daily rates of gross primary productivity and community evapotranspiration, the observed values required correction for average daily solar radiation and evapotranspiration for the month. The latter parameter can be normalized on the basis of average daily pan evaporation. The relationship between community evapotranspiration and pan evaporation was previously established in Chapter V. The conversions and calculations of mean gross productivity were based on the following series of equations.

$$\overline{NPP}_{Lp} = \frac{\bar{I}\ \Sigma \frac{NPP_o}{I_o}}{n}$$

$$\bar{R}_{Dp} = \frac{\Sigma R_{Dp_o}}{n}$$

$$\overline{NPP}_{24} = \overline{NPP}_{Lp} - \bar{R}_{Dp}$$

$$\bar{R}_{24} = 24 \cdot (\bar{R}_{Dp}/\bar{D}p)$$

$$\overline{GPP} = \overline{NPP}_{24} + \bar{R}_{24}$$

$$\overline{ET}_{24} = \frac{\bar{P}\ \Sigma \frac{ET_o}{Po}}{n}$$

where:

$\overline{ET}_{24}$ = mean evapotranspiration in 24 hour day for month

$\overline{NPP}_{Lp}$ = mean net primary productivity during photoperiod

$\bar{I}$ = mean daily total solar radiation for month

NPP_o = observed net primary productivity

I_o = observed total solar radiation (ly/day)

n = replicates

$\bar{R}_{Dp}$ = mean nighttime respiration

R_{Dp_o} = observed nighttime respiration

$\overline{NPP}_{24}$ = mean net productivity in 24 hour day for month

$\bar{R}_{24}$ = mean respiration in 24 hour day for month

$\overline{Dp}$ = mean nighttime period for month

$\overline{GPP}$ = mean gross productivity in 24 hour day for month

$\bar{P}$ = mean 24 hour pan evaporation for month

$\overline{ET}_o$ = observed evapotranspiration for 24 hours

Po = observed 24 hour pan evaporation at Big Cypress Bend station.

From the above series of conversions, the following Table XII-27 presents the mean observed net productivity and respiration rates with one standard error of mean indicated. The second part of the table shows mean estimates of daily community carbon and water metabolism for the months indicated.

Table XII-27. Mean rates of productivity and evapotranspiration for wet prairie communities adjacent (A) and remote (B) to major drainage canals. Productivity rates normalized for equal conditions of total solar radiation. 1972.

			Metabolism (gm C/m^2)		
Site Area	Soil Type	Date 1972	$\overline{NPP}_{Lp}$ ±$S\bar{x}$	$\overline{R}_{Dp}$ ±$S\bar{x}$	No. Replication
A	Oe	June 12	5.26 ± 0.44	4.28 ± 0.22	2
"	"	Oct. 4-6	3.28 ± 0.60	1.34 ± 0.22	4
B	"	Aug. 2-3	4.26 ± 2.0	1.42 ± 0.22	3
"	"	Aug. 7[a]	9.06	4.45	1
"	Od	Aug. 9-14[b]	9.36 ± 2.1	4.97 ± 1.2	4

			Metabolism (gm C/m^2/day or mm H_2O/day)			
		Month	$\overline{GPP}_{24}$	$\overline{R}_{24}$	$\overline{NPP}_{24}$	$\overline{ET}_{24}$
A	Oe	June	10.92	9.24	0.98	3.5
"	"	Oct.	4.60	2.66	1.94	2.6
B	"	Aug.	6.01	3.17	2.84	3.9
"	"	Aug.[a]	14.50	9.89	4.61	4.1
"	Od	Aug.[b]	15.28	10.89	4.39	4.35

[a] Prairie burned April 20, 1972

[b] Prairie burned March 21, 1972

The above reported results have been incorporated into the modeling section. For details of discussion refer to Chapter VI.

XIII - PLANT COMMUNITY STRUCTURE

COMMUNITY SURVEY AND CLASSIFICATION

Communities are often described by their dominant vegetation types. Vegetation, an element both conspicuous and more or less permanent, provides perhaps the most convenient means of characterizing a biological community during brief on-site inspections.

When large tracts of land are involved it is difficult to examine the entire study area and inspect every parcel of land within a reasonable length of time. Some substitute means of survey, other than detailed on-site inspection, must be employed. Soil types and vegetation types are frequently strongly correlated, for vegetation has a great influence on the soil and vice versa. Soil survey maps are often well illustrated and periodically updated by aerial photographs.

The Collier County soil survey (Leighty, et al., 1954) briefly lists the more dominant plants found in each soil type. To further describe the community as to composition and magnitude, one might survey examples of the various communities, and attach soil types and a more detailed list of the plants found in each community. From the aeral extent of the associated soil types (Table XIII-1), the extent of associated plant communities can be determined. The soil type designations in this table refer to the system used in the 1954 soil survey, and are included here to document the area partition of community types used elsewhere in this report.

Habitat Classification

Many communities can be divided into subtly varying habitats. Even though a community as a whole maintains a certain continuity inherent by definition, it still contains distinct zones of different types of vegetation. Vertical zones or habitats may be caused, inter alia, by stratification of light through the various canopy levels. Horizontal zonation may be related to variations in exposure, standing water duration and depth, or by a variety of substrata for rooting and attachment of the plants.

For example, the cypress strand community contains many microhabitats apparently based on exposure to different levels of light, temperature, water, and substratum. The cypress strand contains both aquatic and terrestrial habitats. The strand floor is in many places inundated most of the year. Here aquatic herbs thrive. In this same area, large terrestrial woody plants also live. The cypress strand provides a home for both terrestrial and aquatic plants and animals. The strand floor may contain fishes, crustacea, and insect larvae considered aquatic; but the trees and elevated parts of the strand support terrestrial insects, birds, reptiles, and mammals. Light stratification also separates the strand into various habitats. The various canopy levels contain distinct vegetation types, as is the case for most woody communities. In addition to various light strata and hydroperiods (time of exposure to water), the cypress strand encompasses a variety of substrate, to which distinct plant groups become rooted and attached. These include soil, rock, logs and stumps, and other plants (epiphytic), or surface water (free floating plants).

Table XIII-1. Communities of the Big Cypress and the associated soil types (from Leighty, et al., 1954).

Community	Soil Types
Cypress and hardwood swamp (Strand)	Cf
Cypress with grassy understory	Ob$_5$, Aa$_5$, Pa$_5$, Be$_8$*, and Ra$_9$*
Wet prairie	Ob, Oc, Od, Oe, Of, Be$_7$*, Ra$_3$, Ra$_9$*, Fa, Aa$_3$, Ca$_3$, and Pa$_3$
Sawgrass prairie	Oa, and Tb
Pine	Ob$_2$, Aa, Be, Be$_8$*, Ce, Bb, Bc, Bd, Kb, Ia, Mc, Ra$_2$, Ra$_9$*, Sa, Sc, Ba, Ca, La, and Pa
Sabal (Cabbage palm)	Be, Cd, Bb, Bc, Ka, Kb, Mc, Sc, Ca, Cc, Bc$_4$, Bd$_4$, Ia$_4$, and Pa
Freshwater marsh	Fb
Salt marsh	Ta
Mangrove forest	Mangrove
Estuary and lagoons	Estuary
Misc. (coastal beach, shell mounds, made lands, and coastal hammock)	Cb, Ra, Sb, Ma, and Cb$_6$

* All soils subscripted "8" are divided between pine and cypress; "9" divided among pine, cypress and prairie; "7" divided between prairie and saw palmetto.
Other subscripts indicate the following: "2" - pine; "3" - cabbage palm; "5" - cypress; "6" - coastal hammock

The entire study area can be divided into broad habitat categories as well, such as coastal and upland, or terrestrial and aquatic. These broad categories contain numerous community types. The upland terrestrial habitat includes prairies, hammocks, swamp, marshes, and scrubland communities. The coastal terrestrial habitats include the bay estuary, tidal creeks, tidal pools, coastal river, and brackish pond communities.

These broader habitat descriptions, coupled with community typology and more specific habitat classification within the community, help describe the habitat and niche of individual plant species.

Plant Communities of Southwest Florida

The communities studied were by no means inclusive of all the communities represented in the area. Certain predominant communities were studied, and some less extensive and less "important" communities were excluded.

The coastal intertidal communities studied were mangrove swamp, saltgrass marsh (*Distichilis spicata*), and the spartina marsh (*Spartina spartinae*). The coastal intertidal communities not studied extensively were the black juncus march (*Juncus roemerianus*), the eleocharis marsh (*Eleocharis cellulosa*), and the coastal beach area. The coastal aquatic communities studied included brackish ponds, bays, and inlets of the estuary. All of the area outside of the inland waterways protected by mangrove islands was excluded from study -- for example, offshore reefs and the open sea.

The upland communities studied were cypress swamps, wet prairies, pine and palm hammocks, ponds, sloughs, canals, and roadside ditches. The upland communities excluded from study were the various freshwater marshes, saw grass marsh (*Cladium jamacensis*), cattail marsh (*Typha angustifolia*), and spartina marsh (*Spartina bakerii*). Scrub lands, containing scrub pine (*Pinus clausa*) and the scrub oaks (*Quercus myrtifolia* and *Quercus virginiana* variety *geminata*), were also excluded.

Plants Listed in the Community Descriptions

The plants listed in this description of the communities are restricted phyletically to the vascular plants (*Tracheophyta*), which includes the ferns, fern allies, and the seed plants. The list excludes all algae, some of which are important and are mentioned later in the sections concerning the community in which they are found. The estuary, for example, is particularly rich in marine algae. Canals and ponds contain numerous green and blue-green algae species, diatoms, desmids, and the like. Various blue-green algae are nitrogen fixers in the aquatic and semi-aquatic communities. Certain blue-green algae are producers of soil marl as a metabolic by-product. Marl soils are an important and widespread group of soil types.

The list excludes mosses and liverworts (Bryophyta). Masses of moss occur on the trunks of hardwoods and the sabal palm, as epiphytes, in the cypress slough. Lichens also are excluded, but are common epiphytes in wooden areas. The lichens are generally considered important nitrogen fixers. Fungi are also excluded, even though they are unsurpassed as decomposers of cellulose in both woody and grassy communities. Some fungi are important in mycorrhizal associations, aiding the capture of phosphorus and other nutrients by the roots of many higher plants.

The list of plants in the community is by no means complete, nor should it be considered a checklist for even the plants in the phyla included. The list merely names the more dominant plants and their importance with respect to size, abundance, and where they can be found.

Plant Composition

Cypress Strand

The cypress swamp or cypress strand is composed of cypress (Taxodium) and various hardwood trees and shrubs, together with a variety of ferns, orchids, bromeliads, woody vines, and herbs. The cypress swamp is influenced by a long period of inundation. Only some of the freshwater marshes exceed the cypress strand in length of hydroperiod. The soil and vegetation density and type is highly variable in the cypress strand. In the deep interior of the strand, the soil is rich in organic matter, the level of soil and bedrock is relatively deep, and the vegetation lush, with a dense canopy. Nearer the edge of the cypress strand, the soil becomes sandy to rocky and the vegetation is more sparse. The bedrock and soil are elevated, thus having a shorter period of inundation, resulting in less of the humus accumulation characteristic of the interior strand, due perhaps to more frequent exposure to aerobic conditions. The strand edge is occasionally visited by fire from the adjoining fire sub-climax communities, the prairie and pinelands.

The Strand edge in many ways fits the classic description of an ecotone. However, it is not clearly distinct from the interior cypress strand; rather, there exists a gradual graduation of one into the other. Many of the smaller, more isolated strands contain nothing that resembles a strand interior. Rather, they consist of vegetation only characteristic of the Strand edge. The "Strand edge" type of community includes a large part of the Big Cypress Swamp, perhaps as much as one-half. This massiveness in area does not fit the classic concept of an ecotone as a thin-lined border between two different communities.

Many of the small shrubs, herbs, and trees that are found along the Strand edge cannot become established deeper in the Strand. Their seeds rarely have time to germinate during the dry season before the deep Strand's floor is inundated, drowning the seedlings. Many small trees, shrubs, ferns, and other herbs do, however, become established on the elevated piles of debris on stumps, logs, and at the base of trees in the deep Strand.

Many plants found in great abundance in the deep Strand may not occur at all in the Strand edge or vice versa. For example, many of the ferns found in the deep Strand do not occur at all along the edge of the Strand. The wax myrtle (Myrica cerifera) is the most abundant shrub along the Strand edge, but it is completely absent in the deep Strand. The willow (Salix caroliniana) is most abundant in shallow strand ponds or depressions along marshy borders, but it occurs only occasionally through the rest of the Strand.

The royal palm (Roystonea elata) is found in groves on strand ridges, but is almost completely absent everywhere else in the Strand. Perhaps the only plant found uniformly throughout the cypress strand is cypress itself. Even the cypress show a great variability from the inner strand to the strand edge. Many taxonomists consider the cypress as two distinct species -- the pond cypress (Taxodium ascendens), inhabiting the outer strand, and bald cypress (Taxodium distincum), inhabiting the inner strand.

A list of the plants commonly found in the cypress strand is presented in Appendices AA, BB, CC, DD and EE. Abundance is based on the Strand as a whole, which is by no means homogeneous. The identification of the substratum should give the reader an idea of where the plant can be found in the Strand. Size and abundance is rated relative to other members of the particular group of plants in each table. The species lists were accumulated via field collecting conducted throughout the study period. Abundance values are based on gradient sampling further discussed in Chapter XII.

Prairie

The prairie is characterized by low slender grasses, sedges, rushes, and other herbs. It is basically flat, slightly elevated above the cypress strand which often borders it. The increase in elevation results in a shorter hydroperiod which usually lasts several months, but may be completely absent some years. The bedrock is very near the surface in the shallow phase soils. Rock outcroppings are common. The thin soil layer over the bedrock is poor in humus due to exposure to air and fire. The soil texture is dominated by marl and sometimes fine sand. The shorter hydroperiod apparently is conducive to frequent fires, which may burn the prairies as often as every other year.

Regular fire is essential to the maintenance of the prairie vegetation and soil. Fire regularly kills tree seedlings which have invaded the grassland. Fire removes the debris of dead plant leaves. This removal enhances light penetration for both the herbs and the blue-green algae of the prairie soil. The blue-green algae is responsible for the production of the soil marl. The fire also burns most of the humus deposits on the soil surface. A humus build-up would destroy the alkaline marl and change the entire nature of the soil. In this way, a fire restricts the vegetation to those slender herbs adapted to fire and maintains the soil type.

The soil survey maps list the prairie soil types as various depth phases of Ochopee marl and fine sandy marl (types Oa, Ob, Od, Oe, and Of).

Appendix FF lists vegetation in the prairie (subdivided by monocots and dicots). Some of the prairie plants are normally considered aquatic, and this is mentioned under the column "Growth habitat". These aquatic plants occur most frequently in shallow depressions of the prairie, or in prairies with a relatively long hydroperiod. Like the cypress strand, prairies are not completely homogeneous.

The Pine and Palm Associations

The pine and palm associations are woody plant communities consisting primarily of fire-adapted trees, shrubs, and herbs. The fire sub-climax community is characterized by the South Florida slash pine (*Pinus elliottii* variety *densa*), the cabbage palm (*Sabal palmetto*), and the saw palmetto (*Seranoa repens*) together with various other shrubs and small trees.

The soil for these pine and palm communities is characteristically sandy, rocky, or fine sandy marl. These soils may be very wet or even inundated during part of the year; but they are periodically very dry during the dry season, which encourages fire, and may of itself retard hardwood tree growth.

The various soil types associated with the pine and palm communities are: Arzell fine sand (Aa), Blanton fine sand (Ba), Charlotte fine sand (Ca), Copeland fine sand (Cc, Cd, and Ce), Immokalee fine sand (Ia), Keri-Copeland complex (Ka), Keri fine sand (Kb), Matmon loamy fine sand (Mc), Ochopee fine sandy marl (shallow phase) pine (Ob2), Pompano fine sand (Pa), Rockland (Ra), and Sunniland fine sand

(Sc). The particular pine and palm communities that were investigated in this study are those which are intermingled with the wet prairies and cypress strand. The particular soil associated with these pine and palm communities is the Ochopee fine sandy marl (pine) (Ob2).

Many of the herbs and shrubs in the pine and palm community are also found in the wet prairie and the cypress strand. These plants exhibit a variety of adaptations to fire. Some shrubs and small trees are adapted to fire not by resisting it, but by being able to quickly reseed and complete their life cycle immediately after the fire. The sea myrtle (Baccharis halimifolia), myrsine (Myrsine quianensis), red bay (Persea borbonia), and sweet bay (Magnolia virginiana) are all examples of shrubs and small trees which regularly invade the pine areas after a fire. Wax myrtle (Myrica ceritera), on the other hand, is only killed above ground by fire. Its roots survive and are able to send up new shoots soon after the fire.

The herbs of the pine association are adapted to fire recovery in much the same way as the prairie plants. In fact, many prairie herbs occur in pine and palm associations. The grasses, sedges, and rushes frequently have extensive underground stems (rhizomes) that survive a fire and send up new shoots. Other grass plants re-establish after a fire by seed. Other herbs have various underground parts (tubers, bulbs, corms, and rhizomes) that send up new shoots after the fire. Still others re-establish by seed.

Fire has much to do with the vegetation of the pine and palm communities. Generally, the less frequent the fire or the longer the time since the last fire, the more shrubs and small trees dominate the understory vegetation. After a fire, the slender herbs tend to dominate the ground-cover vegetation.

The pine, cabbage palm, and saw palmetto are well adapted for fire survival. The pine has a thick insulating bark that protects the vital vascular material and cambium of the trunk. The cabbage palm and saw palmetto both have vascular material deeply imbedded throughout their trunks, as numerous vascular bundles. The dispersion of vascular material throughout the stem is characteristic of monocots, and it appears essential to the success of woody monocots like the palm. In addition to diffuse vascular bundles, the saw palmetto's trunk is next to and partly covered by the soil, which affords added protection against fire.

Appendices GG and HH list many of the plants commonly found in the pine and palm associations. The tables are categorized by trees and shrubs, then herbs. The tables give the general size range (even though this is highly variable depending on fire frequency, particularly for woody plants), the abundance (this also is strongly dependent on fire), and the substratum on which the plant lives.

Disturbed Swamplands and Prairies

Plant communities can be stressed and disturbed by many forces, caused by nature or man. The most prevalent activities disturbing the swamplands and prairies of the study area are roadbuilding, drainage, logging, burning, and farming.

Roadbuilding and drainage are the most extensive activities disturbing the natural communities of the study area. Drainage is essential to the genesis of land suitable for residential and commercial development. Roadbuilding is needed to provide access to the developing areas.

Drainage in the swamplands shortens or eliminates the natural hydroperiod, essential for maintaining the community's identity. The continued absence of water on the swamp floor may permit the germination of hardwoods, such as red maple (*Acer rubrum*). The absence of water may reduce the vitality of bald cypress (*Taxodium disticum*) in the swamp.

The drained area cypress slough is marked by a noticeable disturbance of the humus soil layer. There is preponderance of hardwood seedlings and annual and perrenial weeds on the swamp floor; and in many cases a buildup of undecomposed litter on the soil surface is noticeable from the presence of leaves and stems that have not turned into humus.

Roadbuilding through wooded cypress strands involves the physical removal of vegetation and the relocation of soil for the making of roadbeds and ditches. The roadside is first invaded by annual and perrenial weeds, which are fast-growing and quickly seed into the exposed soil. These weeds include *Epatorium* (several species including those called dog-fennel), *Ambrosia artemisiifolia* (ragweed), *Bidens pilosa* (beggar ticks), *Pluchea rosea*, *Phragmites australis* (reed), *Arundo donax* (giant reed), *Rhynchelytrum repens* (Natal grass), *Andropogon virginicus* (broom sedge), *Cyperus planifolius*, *Dichromena colorata*, *Juncus biflorus*, *Juncus polycephalus*, *Boehmeria cylindria* (button hemp), *Amaranthus* sp., *Urena lobata* (Caesar weed), *Sida* sp., *Lantana* sp., and *Hedyotis coryombosa*. After the annual and perrenial weeds, a few vines begin to invade, e.g. *Ipomoea alba* (moon flower), *Sarcostemma clausa*, *Cynanchum* sp. (milkweed vines), and *Mikania batatifolia* (hemp vine).

The cypress tree, a slow grower requiring rather special conditions for seed germination and seedling survival, cannot quickly re-establish on the roadsides. However, other woody plants with fast-growing and quick reseeding capabilities can invade the roadside. The most conspicuous tree which invades the roadside of the cypress strand is the Florida trema (*Trema micrantha*). It is a strikingly fast-growing tree which regularly invades disturbed soil left open to sunlight and exposed to reseeding. Other woody plants invading the cypress strand roads are *Baccharis halimifolia* (sea myrtle) and *Ludwigia peruviana* (water primrose). The latter is particularly prevalent on poorly drained roadsides with wet ditches.

Logging of swamps for cypress timber also has an effect on the vegetation of the cypress strand. The cypress do not quickly re-establish after logging. Hardwoods such as *Salix caroliniana* (willow), *Acer rubrum* (red maple), *Fraxinus caroliniana* (pop ash), and *Ficus aurea* (Florida strangler fig) quickly expand and multiply to fill the gap left by the removal of cypress. Stumps and logging slash provide an excellent substratum for the germination and growth of shrubs, trees, ferns and other herbs. The extreme abundance of ferns, herbs, and small shrubs on debris-covered logs and stumps is noticeable in logged-over cypress swamps.

Burning of the cypress swamp is a rare occurrence. It happens only under abnormally harsh and sustained hot, dry, and drought conditions. The cypress are destroyed and do not recover, and the seedlings grow slowly. The first trees to re-establish after a swamp fire are *Salix caroliniana* (willow), *Fraxinus caroliniana* (pop ash), and *Acer rubrum* (red maple). Burned areas of a cypress swamp show a conspicuous absence of large cypress and an abundance of one or all of the hardwoods mentioned above, especially willow.

Freshwater Ditches and Canals

Freshwater roadside ditches and drainage canals are aquatic communities of the uplands which might also be classified as disturbed communities. The vegetation of these communities is highly variable, depending on water depth, age, water velocity, turbidity, seasonal fluctuation of the water level and bottom type.

Water depth and turbidity together determine the amount of light reaching the bottom of the canal (shoreline vegetation contributes some additional shading effect). Generally, the more light reaching the bottom, the denser is the rooted aquatic vegetation for a given bottom type and current velocity.

Water depth and bottom type also affect the form of the rooted vegetation. Generally emergent vegetation does not occur in water deeper than some minimum depth, nor does it occur on a bottom too hard for suitable anchorage.

Swift-moving canals and ditches tend to have hard or shifting sandy bottoms. The softer muds and silts are washed away. The combination of swift current and poor anchorage eliminates many rooted aquatics.

Floating aquatics tend to inhabit deep, sluggish canals and ditches. The depth discourages rooted aquatics, which compete with the floating plants. However, if the current is swift the floating aquatics are washed downstream.

Seasonal fluctuation of the water level has the greatest effect on the vegetation of shallow canals and ditches, and shallow margins of deeper canals and ditches. These shallow water bottoms are often left exposed to the atmosphere during the dry season. This exposure is fatal to most floating aquatics and many rooted aquatics. However, some rooted aquatics actually benefit from this exposure, e.g. *Diodia virginiana* (buttonweed), cannot flower and produce seed in its emergent form.

The periodic stagnation of shallow roadside ditches and canals results in very high temperatures during the warmer months. This high temperature may stress both plant and animal life in the water by reduction of dissolved oxygen and stepped-up respiratory metabolism.

Table XIII-2 lists the freshwater canals and ditches in the study area, and Appendix II their aquatic plant associations.

Aquatic Communities of the Cypress Strand Lakes and Ponds

The cypress strand typically includes depressions which are filled with water and form a pond or lake. The smaller, shallower depressions form shallow ponds, inhabited by rooted emergent and submergent aquatic plants. The larger, deeper depressions form small lakes inhabited by floating aquatic vegetation and sometimes floating islands. The lakes normally contain water even during the driest of dry seasons, but the ponds usually dry up during the dry season. Both communities are important to fishes as breeding grounds and a place to live during droughts. Such ponds and lakes are often inhabited by alligators. Alligators habitually dig out and deepen the ponds and lakes during the dry season, thus aiding the survival of fish and fish-eating birds.

Table XIII-2. Freshwater canals and ditches in the study area.

Station	Water Depth	Water Velocity	Seasonal Flux	Bottom
GAC canal system (GAC) (above the weir)	2-4 meters narrow margins except at the weir	Sluggish headwaters, moderate downstream, sluggish margins	Water velocity variable, water depth less variable	mostly sandy limestone, muds over limestone
James Scenic Drive (JD)	Usually less than 1½ meters	Mostly sluggish, seasonally stagnate to moderate	Most parts exposed during dry season	Sandy, rocky and organic muds and silts
Tamiami Canal (TC) (west of Royal Palm Hammock)	1-4 meters, narrow margins	Mostly sluggish	Seasonally variable but rarely exposed except the margins	Sandy, rocky and organic
Alligator Alley (AA)	1-4 meters, mostly narrow margins, some broadened margins	Mostly sluggish	Seasonally variable margins, exposed during dry season	Sandy, rocky and organic
Miscellaneous roadside ditches and canals (misc)	Variable up to 3 meters	Variable, mostly sluggish	Variable, mostly seasonal exposure	Variable

The strand lake studied in the study site is referred to as Ballard's Lake, The floating vegetation consisted mostly of *Pistia stratiotes* (water lettuce), along with *Eichhornia crasspies* (water hyacinth), *Lemna perpusilla* (duckweed), and *Limnobium spongia* (frogbit). The lake's margin consisted of *Zizaniopsis miliacea* (giant cutgrass), *Saururus cernuus* (lizard's tail), and *Cephalanthus occidentalis* (button bush). Ballard's Lake also had numerous small floating islands, mostly less than a meter in diameter and about 10 to 20 centimeters thick. These islands were composed of a dark, well-decomposed organic material. The vegetation on them consisted of *Ludwigia leptocarpa* and *L. peruviana* (water primrose), *Pluchea purpurascens*, *Amaranthus* sp., and *Cyperus* sp.

These floating islands are not typical of all small strand lakes, e.g. Corkscrew Swamp's water lettuce lake has few such floating islands. Floating islands of this sort are described by Craighead (1971). He mentions their distribution in the Everglades National Park and speculates on their origin.

Several strand ponds were observed in the study area. These ponds appear to be depressions similar in depth to the sawgrass marsh, but much less extensive and protected from fire and sawgrass invasion by the surrounding cypress swamp. The emergent vegetation consists of *Thalia geniculata* (fire flag), and *Sagittaria lancifolia* (arrowhead), and occasionally *Canna flaccida*. This herbaceous aquatic zone is often fringed by *Salix caroliniana* (willow). The pond margin consists of a few small emergent and submergent aquatics such as *Juncus polycephalus* (rush), *Sagittaria graminea* (arrowhead), *Bacopa caroliniana*, *Ludwigia repens*, and *Pontideria lanceolata* (pickeralweed). These ponds are often circled by a line of *Annona glabra* (pond apple) and *Fraxinus caroliniana* (popash).

Salt Marshes and Mangrove Swamps

The coastal intertidal habitat consists of grassy communities (salt marshes) and woody communities (mangrove swamp, coastal hammocks, and coastal beach). The coastal hammocks and coastal beach were not studied, as they were not considered extensive enough or important enough in the study area to warrant priority over the mangrove swamp. Mangrove swamps are quite extensive throughout the coastal habitat (Figures XIII-1 and 2).

The salt marsh types studied most extensively were the saltgrass marsh, consisting of mostly Distichlis spicata (saltgrass) and Salicornia bigelovii (glasswort) along with scattered Spartina spartinae, and the cordgrass marsh, consisting mostly of Spartina spartinae (cordgrass) along with scattered patches of Distichlis spicata (salgtrass), Eleocharis cellulosa (spike rush) and Sesuvium portulacastrum (sea purslane).

Various other saltmarsh communities include: the black juncus marsh (Juncus roemerianus), the spike rush marsh (Eleocharis cellulosa), and the saltwort marsh (Batis martima) (Craighead, 1971).

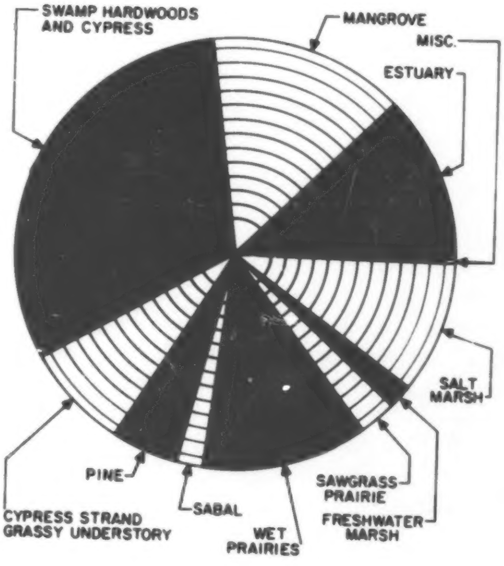

Figure XIII-1. Distribution of communities in the study area.

The saltgrass marsh is characterized by moderate salinity (20 ppt); daily or twice daily flooding with high tide; numerous marine invertebrates such as snails, mussels, and polychetes; and a noticeable amount of periphytic green algae.

In contrast to the saltgrass marsh, the cordgrass marsh is characterized by low salinity (5 ppt); few or no snails, mussels, or polychetes; irregular inundation occurring only during very high tides and overland freshwater flow; and little periphytic algae. In general, the marine influence in the cordgrass marsh is greatly reduced by the miles of river, mangrove swamp, bays, and mangrove islands separating the marsh from the Gulf of Mexico.

This cordgrass marsh is of a different species and a completely different habitat from the *Spartina alterniflora* marsh which is common from Central Florida to Texas westward, and to New England northward.

The *Spartina alterniflora* marsh, in contrast to the *Spartina spartinae* marsh in South Florida, tolerates high salinity, wave action, and tidal fluctuation. It is located right on the shores of the Atlantic and the Gulf of Mexico. A small *Spartina alterniflora* marsh is reported to exist near Little Marco Pass (near Marco Island), but this marsh type as a whole is rare in the Ten Thousand Islands.

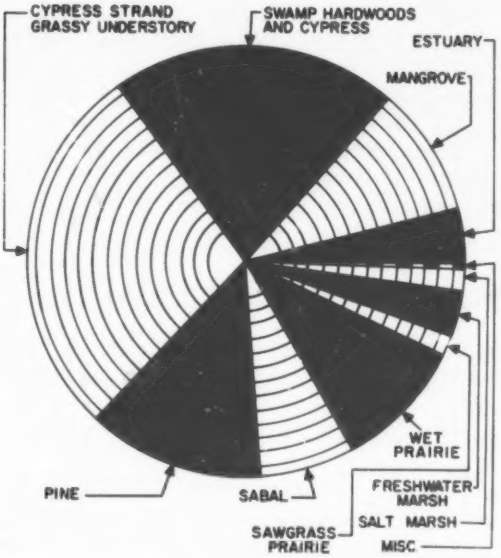

Figure XIII-2. Distribution of communities in the Big Cypress Swamp (includes Fahkahatchee).

The mangrove swamps and islands of South Florida consist of four major tree species: *Rhizophora mangle* (red mangrove), *Laguncularia racemosa* (white mangrove), *Avicennia nitida* (black mangrove) and *Conocarpus erecta* (buttonwood). The distribution of these species is dependent on water depth and salinity. The red mangrove, with its extensive prop root system and special reproductive fruits, can inhabit the deepest waters. It is conspicuous along shorelines of bays, rivers, and islands. The black mangrove is adapted to shallower water with its pneumatophores (protrusions of the roots through the soil to aid root respiration). The black mangrove is conspicuous interior to the red mangroves on shores of bays, rivers, and larger islands. It is also present on the steeper, more elevated banks of rivers and canals.

The white mangrove, like the black, shows a pneumatophore adaptation. The white usually inhabits sandy or shelly soil, in contrast with the rich organic soil inhabited by the black mangrove. The white mangrove is a fast grower and quickly invades areas disturbed by storm or dredging.

Buttonwood is another woody plant associated with mangroves. Buttonwood is not commonly found in areas of high salinity or high tidal influence. Buttonwood has no special root adaptation for standing water, but it can inhabit the more elevated coastal areas where salinity eliminates upland trees. Buttonwood occurs right up to the point of termination of salinity and tidal influence.

Numerous salt-tolerant herbs are associated with mangroves, particularly on elevated portions of the mangrove swamp. These herbs include *Acrosticum aureum* (leather fern), *Acrosticum danaeaefolium* (leather fern), *Fimbristylis spathacea*, *Fimbristylis castanea*, *Yucca aloifolia* (Spanish bayonet), *Hymenocallis latifolia* (spider lily), *Batis maritima* (saltwort), *Salicornia bigelovii* (glasswort), *Suaeda linearis* (sea blite), *Alternanthera ramoissima* (chaff flower), *Philozerus vermicularis* (samphire), *Iresine celosia* (bloodleaf), *Trianthema portulacastrum*, *Sesuvium portulacastrum* (sea pursland), *Opuntia compressa* (pricklypear cactus), *Opuntia stricta* (pricklypear cactus), *Iva frutescens* (marsh elder), *Borrichia frutescens* (sea daisie), and *Borrichia arborescens* (sea oxeye). In addition to these ground-cover herbs, several species of bromeliads (Bromeliaceae) are found as epiphytes in mangroves in the moderate to lower salinity areas. Also three lianas are common among the mangroves in the study area -- *Hippocratea volubilis*, *Rhabdadenia biflora* (rubber vine), and *Ipomoea tuba* (moon vine).

Aquatic Coastal Communities

The aquatic coastal communities in the study area comprise bays, inlets, coastal rivers, brackish-water lakes and lagoons, and coastal canals. The distribution of the various plants in the coastal aquatic communities is strongly related to salinity, bottom type, water depth, and currents.

Benthic estuarine plants occur only in shallow waters with weak currents and good light penetration. The rooted benthic vegetation cannot survive on bottoms that are constantly shifting or experiencing a large amount of erosion or sedimentation.

The bay estuary is characterized by rooted vegetation such as *Thalassia testudium* (turtle grass), *Halophila engelmannii* (sea grass), *Diplanthera wrightii*, and several species of marine algae. The bay estuary experiences high salinities and a large degree of tidal fluctuation. It is separated from the Gulf only by scattered mangrove islands. Coastal rivers contain rooted benthic vegetation only on shallow, stable, sandy bottoms. The depth and current of the mainstream river produces a bottom unsuitable for benthic vegetation. The river vegetation is highly variable, depending on salinity. Near the bays, where salinity is highest, the vegetation is similar to that found in the bay. *Diplanthera wrightii* is particularly prevalent.

Brackish-water lakes and lagoons in the study area are located in the upper reaches of the rivers. They are actually broad, shallow expanses of the river bordered by mangrove and saltmarshes, principally *Spartina spartinae* marsh and *Distichilis spicata* marsh. These brackish-water lakes and lagoons are characterized by low to moderate salinity and reduced tidal influence.

The benthic vegetation of moderate salinity (10-20 ppt) lakes and lagoons consist mostly of *Ruppia maritima* (widgeon grass). The lakes and lagoons farther up the rivers with lower salinity (less than 5 ppt) consist of *Chara* sp. and *Najas marina* (marine niad).

Coastal canals generally are lacking in benthic vegetation except along the margins. The combination of depth, current, and boat traffic, reduce the amount of light reaching the bottom and the stability of the bottom (increased sedimentation and resuspension).

XIV - MACROBENTHOS

INTRODUCTION

A study of macrobenthic invertebrates was undertaken with several views in mind. First, numbers and kinds of invertebrate animals inhabiting an area can be indicators of changes in the physical and chemical quality of the substrate and surrounding water. Secondly, the benthic faunal community serves as a food resource for numerous fish species, many of which are of important commercial and sport value. Finally, results of such a study would serve as background information for determining future changes in the benthic invertebrate resources.

METHODS

Both Fahkahatchee and Fahka Union Bays were sampled for macrobenthos during March 28-30, June 20-21, and September 24-28, 1972. A stratified sampling program design resulted in 18 sampling stations in Fahka Union Bay (six mud, six sand, and six shell) and 26 stations in Fahkahatchee Bay (ten mud, ten sand, and six shell). Because of the absence of large areas of sand and shell substrates in Fahka Union Bay, it was necessary to duplicate samples at two shell sites in order to obtain the desired number of samples. However, when more than one sample was taken from one location (within a predetermined grid), the boat was moved approximately 10 to 15 meters away from the first site. The sampling station locations are presented in Figure XIV-1.

Two samples were collected and composited at each station by use of a 15.2 cm by 15.2 cm (6 in. by 6 in.) Ekman dredge, resulting in a total area of 232 square centimeters (0.5 square feet). A slurry was made from each composite sample contents and sieved through a No. 30 sieve. The organisms and other material retained in the sieve were removed into a glass jar which was subsequently filled with ethanol and a small amount of sodium bicarbonate. The samples were forwarded to the Biological Services Branch, Surveillance and Analysis Division, Environmental Protection Agency, in Athens, Georgia, for identification and biomass determinations.

Decapod crustaceans collected in the monthly fish trawling samples at regular stations in the estuary were sorted, identified, and tabulated. During the year, the collections numbered 24 otter and 23 surface trawls in Fahka Union Bay; while in Fahkahatchee Bay, there were 67 otter and 69 surface trawls. Freshwater decapods were obtained monthly in samples from a square-meter drop frame at two sites in Fahkahatchee Strand. Some special collections were made at estuarine locations not included in the routine fish sampling scheme. Descriptions of collection gear, sampling procedure, and station locations are given in Chapter XV.

RESULTS AND DISCUSSION

A taxonomic breakdown of benthic organisms found during the course of the study is presented in Appendix JJ. Table XIV-1 summarizes the data on biomass in the two bays. The data were analyzed by analysis of variance, using a log transformation (Snedeson, 1956). Two-way ANOVA (neglecting interaction)

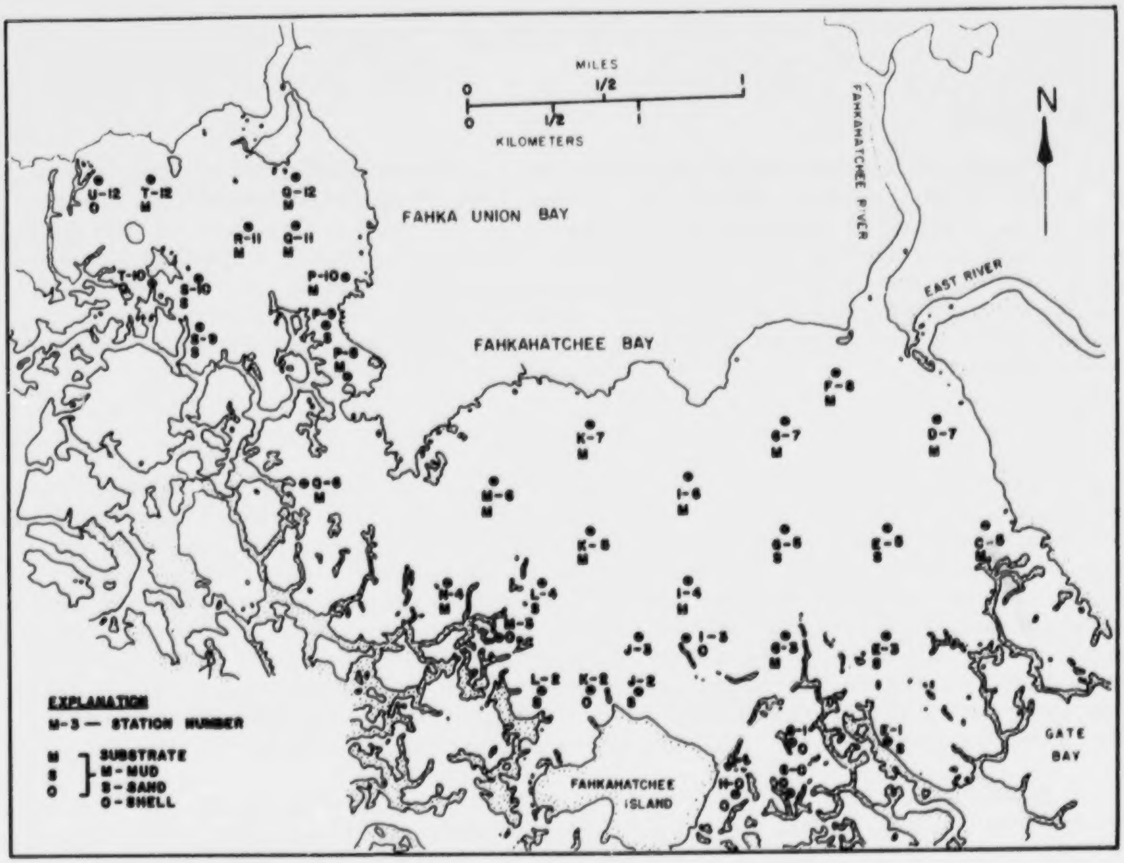
MILES
0
1/2
1
0
1/2
1
KILOMETERS
N
FAHKA UNION BAY
FAHKAHATCHEE BAY
FAHKAHATCHEE RIVER
EAST RIVER
GATE BAY
FAHKAHATCHEE ISLAND
U-12 O
T-12 M
Q-12 M
R-11 M
Q-11 M
T-10 S
S-10 S
P-10 M
P-9 S
S-9 S
P-8 M
O-6 M
M-6 M
K-7 M
F-8 M
G-7 M
D-7 M
I-6 M
K-5 M
G-5 S
E-5 S
C-5 M
N-4 M
L-4 S
M-3
I-4 M
J-3
I-3 O
G-3 M
E-3 S
L-2 S
K-2 O
J-2 S
G-1 O
E-1 S
H-0 O
G-0
EXPLANATION
M-3 — STATION NUMBER
M
S
O
SUBSTRATE
M-MUD
S-SAND
O-SHELL

Figure XIV-1. Station locations for macrobenthos study.

revealed a lack of significant (5-percent level) differences either by bay, by date, or by substratum both within and between bays.

The (arithmetic) mean number of individuals captured per sampling, segregated by bay and by substratum, is shown in Figures XIV-2 through 4. The only significant differences (based on paired-sample t tests) reside in the observations on Isopoda. However, most of the difference is due to the June sampling points. This coincided with an increase in the standing crop of decapods as measured in the catches of the otter and surface trawls.

The relative numerical abundance of decapods from the bays and adjacent areas is presented in Table XIV-2. The monthly occurrences of crustaceans are listed in Table XIV-3.

During our investigation, the commercially important pink shrimp (Penaeus duorarum) was the most abundant decapod crustacean in our collections. Pink shrimp were extremely numerous in the marine grass beds in north Fahkahatchee Bay. Peak catches were trawled during July and November, which indicated a seasonal pattern of availability.

Table XIV-1. Biomass of macrobenthos. Values as arithmetic mean ±1 S.E. (geometric mean), gm/m^2.

	Mud Substrate	Sand Substrate	Shell Substrate
		Fahkahatchee Bay	
March - a	1.78±0.38(1.42)	3.02±0.74(2.18)	10.7±3.09(8.11)
March - b	1.04±0.27(0.77)	1.24±0.42(0.82)	3.55±1.28(2.33)
June - a	2.59±0.53(2.09)	5.77±3.50(2.56)	2.34±0.52(2.33)
June - b	1.12±0.28(0.82)	2.70±1.81(1.06	1.10±0.30(0.91)
September - a	3.44±1.34(1.89)	5.33±1.81(3.95)	5.91±3.80(2.48)
September - b	1.22±0.40(0.78)	2.23±0.84(1.45)	2.13±1.38(0.92)
		Fahka Union Bay	
March - a	2.36±0.68(1.40)	2.02±0.68(1.25)	0.84±0.21(0.68)
March - b	1.38±0.38(0.84)	1.01±0.33(0.60)	0.42±0.10(0.36)
June - a	5.31±1.03(4.70)	4.26±1.28(3.40)	1.78±0.52(1.37)
June - b	2.86±0.63(2.48)	1.83±0.46(1.57)	0.87±0.27(0.49)
September - a	2.19±0.47(1.93)	3.08±1.75(1.74)	1.40±0.27(1.19)
September - b	1.06±0.22(0.94)	1.04±0.42(0.78)	0.50±0.10(0.45)

a - Dry weight values
b - Ash-free dry weight

The mean number and biomass (wet weight) of pink shrimp and grass shrimps (*Palaemonetes vulgaris*, *P. intermedius*, and *P. pugio*) per unit-of-effort are compared in Figures XIV-5 and 6 respectively.

The decopods are important faunal components in estuarine food chains. Numerous crustaceans--for instance, *Palaemonetes intermedius* and *Rithropanopeus harrisii*--consume large quantities of vascular plant detritus and algae (Odum and Heald, 1972). In turn, grass shrimps, pink shrimp, swimming crabs (Portunidae), mud crabs (Xanthidae), and other decapods often are major food items in the diets of sport and commercial fishes, including spotted seatrout (Stewart, 1961); gray (mangrove) snapper (Croker, 1960); red drum (Yokel, 1966); snook (Marshall, 1958); ladyfish; and silver perch.

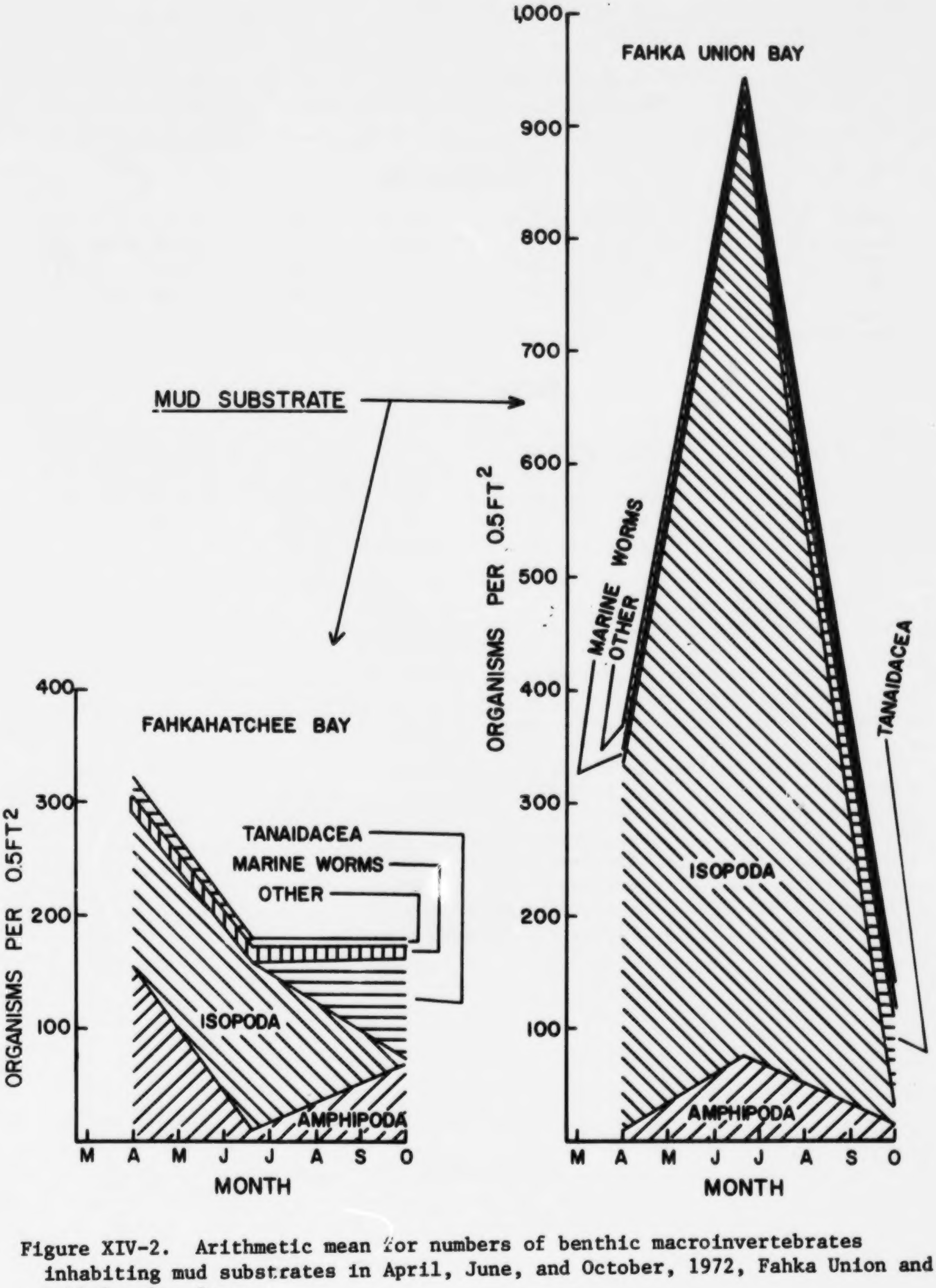

Figure XIV-2. Arithmetic mean for numbers of benthic macroinvertebrates inhabiting mud substrates in April, June, and October, 1972, Fahka Union and Fahkahatchee Bays.

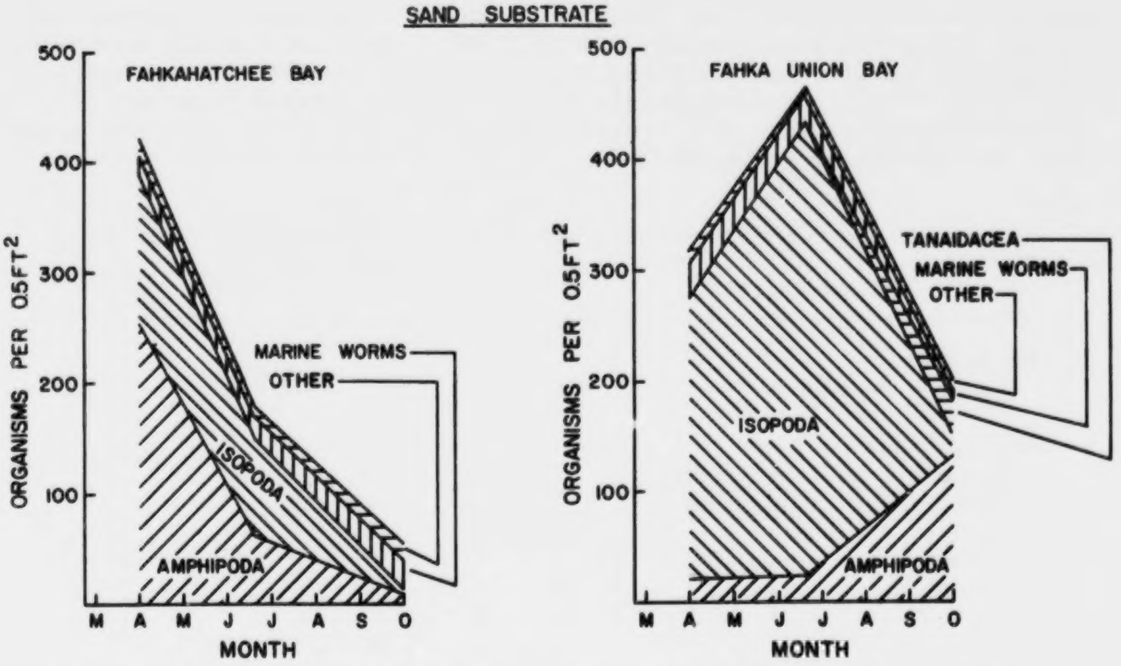

Figure XIV-3. Arithmetic mean for numbers of benthic macroinvertebrates inhabiting sand substrates in April, June, and October, 1972, Fahka Union and Fahkahatchee Bays.

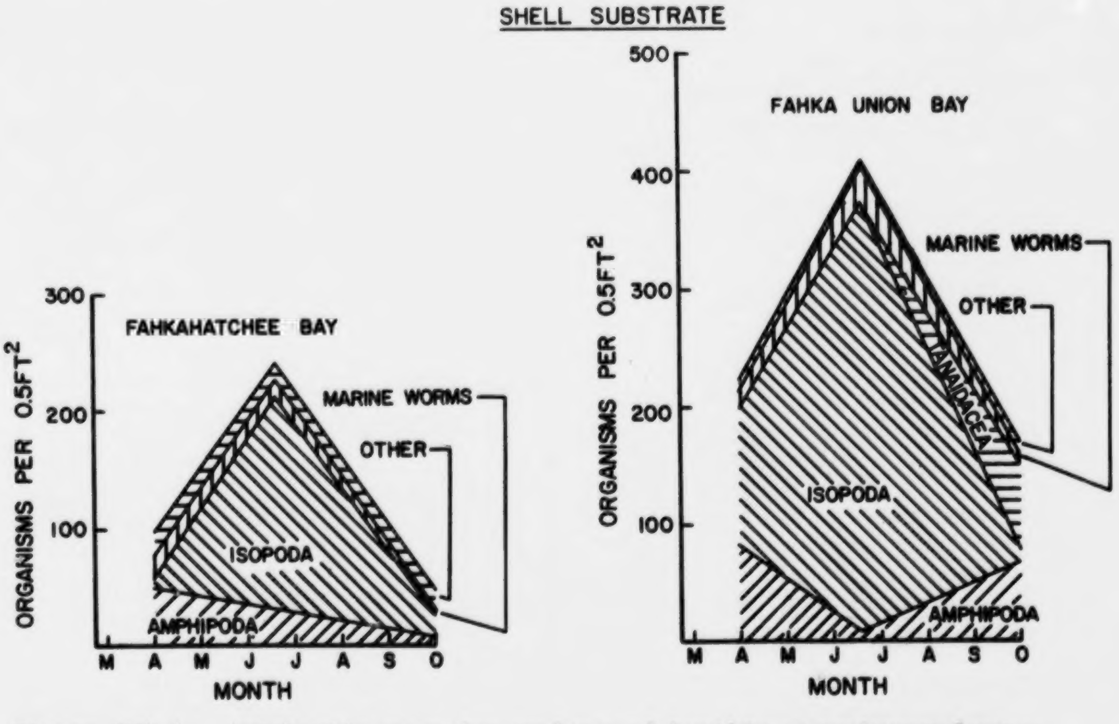

Figure XIV-4. Arithmetic mean for numbers of benthic macroinvertebrates inhabiting shell substrates in April, June, and October, 1972, Fahka and Fahkahatchee Bays.

Table XIV-2. Distribution and relative abundance of decapod crustaceans collected in Ten Thousand Islands, Florida, 1972. Most individuals were taken in association with monthly fish collections while employing otter and surface trawls. Habitat designations were as follows: Fahka Union Bay (A); Fahkahatchee Bay - West (B), - North (C), - East (D); other estuarine areas (E); and freshwater sites (F).

Family and Species	Habitat					
	A	B	C	D	E	F
Penaeidae						
Penaeus duorarum	355	357	1655	522		
Palaemonidae						
Periclimenes longicaudatus	2	5	246	14		
Periclimenes americanus	3	9	42	6		
Leander paulensis	32	8	8	1		
Palaemonetes paludosus						24
Palaemonetes vulgaris	15	6	14	58		
Palaemonetes intermedius	21	91	1430	162		
Palaemonetes pugio	1	2	26	12		
Alpheidae						
Alpheus normanni	1			8		
Alpheus heterochaelis		1	5	5		
Hippolytidae						
Thor floridanus			4			
Hippolyte pleuracantha		45	422	134		
Tozeuma carolinense		57	365	114		
Astacidae						
Procambarus alleni						514
Porcellanidae						
Petrolisthes armatus		2	8	7		
Porcellana sayana					2	
Paguridae						
Paguristes spp.		2	9	33		
Pagurus longicarpus			a	a		
Pagurus bonairensis	a	a	a	a	a	
Portunidae						
Portunus sayi	2	2	6			
Portunus gibbesii	2	7	2			
Callinectes sapidus	27	22	12	24		
Callinectes ornatus	5	14	11	25		
Xanthidae						
Menippe mercenaria			1		1	
Rhithropanopeus harrisii					1	

Table XIV-2. Distribution and relative abundance of decapod crustaceans collected in Ten Thousand Islands, Florida, 1972. Continued.

Family and Species	Habitat A	B	C	D	E	F
Neopanope texana	23	161	70	221		
Eurypanopeus depressus		1	7	15		
Panopeus herbstii		1				
Goneplacidae						
Eucratopsis crassimanus					1	
Grapsidae						
Aratus pisonii					8	
Ocypodidae						
Uca rapax					10	
Uca pugilator					51	
Majidae						
Libinia dubia	12	17	38	42		

[a] Numerical data on *Pagurus* spp. were only recorded from a few collections.

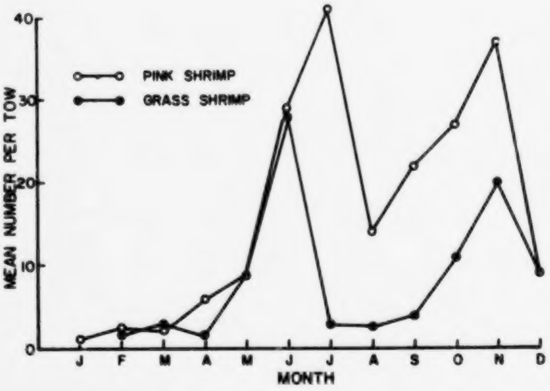

Figure XIV-5. Monthly numbers of pink shrimp (*Penaeus duorarum*) and grass shrimp (*Palaemonetes* spp.) taken from combined catches of surface and otter trawls in Fahka Union and Fahkahatchee Bays, 1972.

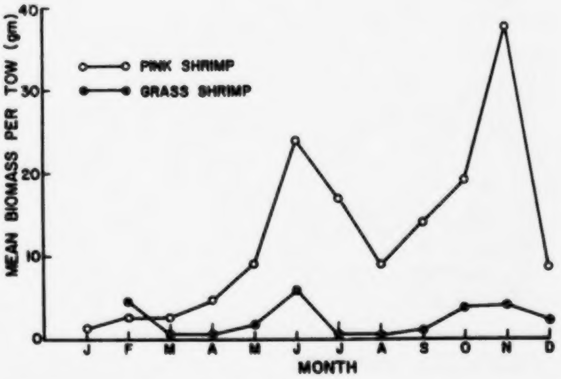

Figure XIV-6. Mean monthly biomass, wet weight, of pink shrimp (*Penaeus duorarum*) and grass shrimp (*Palaemonetes* spp.) taken from combined catches of surface and otter trawls in Fahka Union and Fahkahatchee Bays, 1972.

Table XIV-3. Temporal distribution of decapod crustaceans collected in Ten Thousand Islands, Florida, 1972. Species not taken in association with monthly fish collections appear in parentheses.

Family and Species	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Penaeidae												
Penaeus duorarum	x	x	x	x	x	x	x	x	x	x	x	x
Palaemonidae												
Periclimenes longicaudatus	x	x	x	x						x	x	x
Periclimenes americanus		x	x		x	x			x	x	x	x
Leander paulensis	x									x	x	x
Palaemonetes paludosus			x	x					x	x	x	x
Palaemonetes vulgaris		x	x	x	x	x	x	x	x	x		
Palaemonetes intermedius	x	x	x	x	x	x	x	x	x	x	x	x
Palaemonetes pugio			x			x				x		x
Alpheidae												
Alpheus heterochaelis	x	x								x		x
Alpheus normanni										x	x	x
Hippolytidae												
Thor floridanus										x		
Hippolyte pleuracantha					x	x	x	x	x	x	x	x
Tozeuma carolinense	x	x	x	x	x	x	x	x	x	x	x	x
Astacidae												
Procambarus alleni	x	x	x	x			x	x	x	x	x	x
Porcellanidae												
Petrolisthes armatus		x	x		x	x	x			x		x
Porcellana sayana	(x)											
Paguridae												
Paguristes spp.						x				x	x	x
Pagurus longicarpus[a]						x						
Pagurus bonairensis[a]	x	x	x	x	x	x	x	x	x	x	x	x
Portunidae												
Portunus sayi					x	x						
Portunus gibbesii			x		x			x				
Callinectes sapidus	x	x	x	x	x	x	x	x		x	x	x
Callinectes ornatus				x	x	x	x	x	x	x	x	x
Xanthidae												
Menippe mercenaria		x										
Rhithropanopeus harrisii						x						
Neopanope texana	x	x	x	x	x	x	x	x	x	x	x	x
Eurypanopeus depressus			x			x						x
Panopeus herbstii								x				
Goneplacidae												
Eucratopsis crassimanus				(x)								
Grapsidae												
Aratus pisonii												(x)
Ocypodidae												
Uca rapax				(x)				(x)				(x)
Uca pugilator				(x)				(x)				(x)
Majidae												
Libinia dubia	x	x	x	x	x	x	x	x	x	x	x	x

[a] Data Incomplete

XV - FISHES OF FAHKAHATCHEE STRAND AND TEN THOUSAND ISLANDS

INTRODUCTION

There have been few systematic surveys of the marine fishes in Southwestern Florida. Historically, Lonnberg (1894) and Longley and Hildebrand (1941) described the fish fauna of the southwest coasts and Florida Keys, respectively. Evermann and Kendall (1900) prepared a checklist of Florida fishes. In recent times, the most comprehensive surveys of fishes were conducted by Tabb and Manning (1961) in Whitewater and Florida Bay and by Roessler (1967) in Buttonwood Canal; these areas are in Everglades National Park near Flamingo. Gunter and Hall (1965) investigated the fishes of the Caloosahatchee River and adjacent estuaries near Fort Myers, Florida. The fishes of the Charlotte Harbor area were studied by Wang and Raney (1971).

Various aspects of the life histories of single fish species have been conducted in the Everglades area. Investigations by Croker (1960) on gray snapper (*Lutjanus griseus*), Steward (1961) and Moffett (1961) on spotted seatrout (*Cynosion nebulosus*), Yokel (1966) on red drum (*Sciaenops ocellata*), Waldinger (1968) on three species of mojarras (*Gerreidae*), and Volpe (1959) and Marshall (1958) on snook (*Centropomus undecimalis*) have contributed important information on the biology of these fishes. In addition, Odum and Heald (1972) studied energy flow pathways of 45 fish species in Whitewater Bay and North River, and Hunt (1953) reported on the food habits of the Florida gar (*Lepisosteus platyrhincus*) and associated freshwater fishes in the Tamiami Canal.

Little information is available concerning the fishes of the Fahkahatchee Strand and Ten Thousand Islands. The importance of these waters as aquatic habitats for freshwater and estuarine fishes has not been documented. To help fill this void in the information, we initiated fisheries investigations to establish baseline data for the year 1972. The objectives of our studies were (1) inventory of fishes for these two areas, (2) determine the seasonal distribution and relative and absolute abundance of these fishes, and (3) assess fish community structure as related to habitat and other aspects of environmental conditions.

STANDING CROPS OF FISHES

Habitats, Sampling Procedures and Gear

Freshwater fish communities were sampled at two temporary waterways (seasonally inundated borrow canals) in Fahkahatchee Strand (Stations A_1 and A_2), in a drainage canal adjacent to the western edge of Fahkahatchee Strand (Station B), in a tidal canal paralleling the Tamiami Trail (Station C), and in a natural lake, locally known as Ballard's Lake (Station D) in Fahkahatchee Strand. Estuarine fish communities were studied at three sites in Fahka Union Bay (Stations E, F, and G), at three sites in Fahkahatchee Bay (Stations H, I, and J), and in a tidal stream in north Fahkahatchee Bay (Station K). These stations are depicted in Figure XV-1.

Several techniques were used to enclose or block the water columns. Each was designed to obtain the maximum return from a given area. Because of the shallow depths and intermittent periods of inundation, the gear for sampling

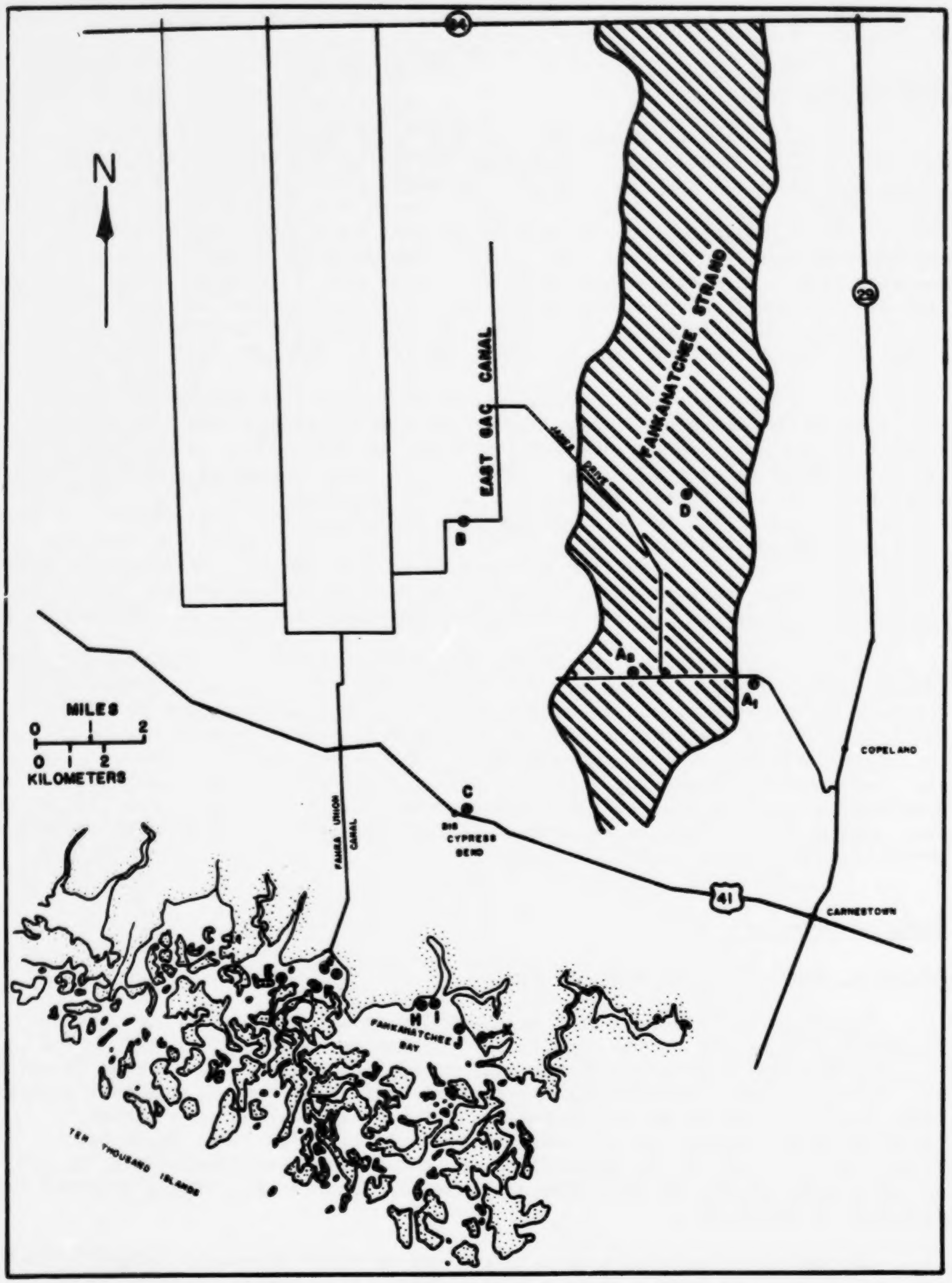
84
N
EAST SAC CANAL
JANES DRIVE
FAHKAHATCHEE STRAND
29
B
D
A2
A1
MILES
0 1 2
0 1 2
KILOMETERS
COPELAND
C
BIG CYPRESS BEND
FAHKA UNION CANAL
41
CARNESTOWN
H
I
J
FAHKAHATCHEE BAY
TEN THOUSAND ISLANDS

Figure XV-1. Study area and sampling sites in Fahkahatchee Strand and the Ten Thousand Islands, Florida. Dots designate the stations for the standing crops of fishes.

animal populations at the two temporary waterways in Fahkahatchee Strand (Stations A_1 and A_2) consisted of a m^2-frame and 5.0 percent emulsified rotenone, a fish toxin. The frame was dropped over an undisturbed area, mud was stacked around the outer bottom edges of the frame to prevent escapement, and emulsifiable rotenone was added to produce a dosage of about 1.5 ppm in the entrapped water. Following the removal of the aquatic vegetation in the m^2-area, dip nets with square hoops were repeatedly swept back and forth until all the fishes, amphibians, and crustaceans were collected. The top 2.5 cm of bottom debris was examined for killifishes (Fundulus spp.) and crayfish (Procambarus alleni) that often burrowed into the substrate.

Two nets were used to block off a 100 meter stretch of stream in the eastern branch of the GAC Canal (Station B) and in the Tamiami Canal (Station C). One block net was 30.5 m long and 1.8 m in depth with 6.4 mm-bar mesh netting, while the other was 21.3 m long and 1.8 m in depth with 12.8 mm-bar mesh. Nets were stretched across the canal and anchored securely to the mud bottoms with steel fence posts. The study areas received emulsifiable rotenone at a concentration of approximately 1.5 ppm. Immobilized fishes that surfaced were dipped from the water. An estimate of the number of dead fishes that sank to the bottom was obtained from the recovery of individuals in m^2-wire baskets that were randomly spaced throughout the study section. Later, to aid in the detoxification of the rotenone, potassium permanganate was dispersed downstream.

Emulsifiable rotenone was applied to the waters of Ballard's Lake (Station D) at a concentration of 2.0 ppm. Floating fishes were dipped from the lake on the day of poisoning, as well as on the following day. Due to natural processes of biological decay, we assumed that the majority of dead fishes that initially sank to the bottom had floated to the surface by the second day.

Estimates of the standing crops of estuarine fishes in Fahka Union (Stations E, F, and G) and Fahkahatchee Bays (Stations H, I, and J) were obtained by enclosing the water column with a 6.4 mm-bar mesh net that was 274.3 m (900 feet) long and 3.0 m deep. A rectangular sampling area was formed using four corner posts. The net was then eased off the bow of the boat around the corner posts. To prevent escapement, the lead line was pushed into the soft substrates.(1)

Fishes were recovered by repeatedly seining through the enclosed areas until the yield was negligible. The number of seine hauls per study site varied from three to seven. The few fishes that were not recovered generally were small individuals such as gobies (Gobiidae), pipefishes (Syngnathidae), and anchovies (Engraulidae).

Block nets and rotenone were used to sample the fish community of the tidal stream (Station K) that emptied into Fahkahatchee Bay. The downstream net was set across the mouth of the stream early in the morning on a high tide. As the waters receded, the net prevented escapement of fishes from the stream and into the bay. On the following low ebb tide, the shallow upstream segment of the study area was blocked off, and rotenone was applied to the water to give a concentration of 2.0 ppm.

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(1) Equipment for this phase of the study was provided on loan by the Florida Freshwater Fish and Game Commission. The study was conducted as a cooperative effort with the University of Florida, Center for Aquatic Sciences.

The temporary waterways in the Strand (Stations A_1 and A_2) were sampled monthly, while the other study sites were only sampled once.

Fishes were separated by species, counted, measured, and weighed. Generally, large fishes were processed in the field, while small individuals were preserved in a 10 percent solution of formalin and returned to the laboratory for examination.

All length measurements in this chapter were total length (anterior extremity with the jaws closed to the tip of the compressed caudal lobes) to the nearest 1.0 mm, unless stated otherwise. Wet weights (biomass) of the fishes were taken with either a beam balance (20-kg capacity) or a dial type balance (1,600-gm capacity) to the nearest 1.0 or 0.1 gm, respectively.

The names of fishes and their phylogenetic order follow the recommendations of the American Fisheries Society (Bailey, *et al*., 1970). A tabulation of the common and scientific names of fishes collected from Fahkahatchee Strand and the Ten Thousand Islands appears in Appendix KK.

Results

Temporary Freshwater Habitats

At the two freshwater sites (Stations A_1 and A_2), the major biological components were fishes (12 species), amphibians (2 species), macrocrustaceans (2 species), and aquatic vascular plants (10 species) (Table XV-1).

The standing crops of fishes by biomass (wet weight) ranged from 1.1 to 172.8 gm/m^2, excluding the months of May and June when the study sites were dry. The mean biomass for the year was 44.3 gm/m^2. The mean number of fishes per m^2 varied from 3.5 to 575.0 individuals. The lowest observed values by biomass and by number occurred during the wet season (summer and fall), while the highest values were recorded during the dry season (winter and spring).

The freshwater fishes in the temporary waterways belonged to the following families: Poeciliidae (livebearers), Cyprinodontidae (killifishes), Centrarchidae (sunfishes), and Ictaluridae (catfishes). The species composition in decreasing order of abundance was composed of mosquitofish (*Gambusia affinis*), flagfish (*Jordanella floridae*), sailfin molly (*Poecilia latipinna*), least killifish (*Heterandria formosa*), marsh killifish (*Fundulus confluentus*), yellow bullhead (*Ictalurus natalis*), spotted sunfish (*Lepomis punctatus*), bluefin killifish (*Lucania goodei*), Everglades pygmy sunfish (*Elassoma evergladei*), warmouth (*Lepomis gulosus*), bluegill (*L. macrochirus*), and golden topminnow (*Fundulus chrysotus*). Mosquitofish, flagfish, sailfin molly, and least killifish were the major fishes and represented 61.2, 20.9, 6.6 and 4.0 percent, respectively, of the total catch. On occasion, the Florida gar (*Lepisosteus platyrhincus*) was sighted in the waterways, but was never taken in the sampling gear.

The abundance of fishes in Fahkahatchee Strand was directly related to the seasonal water patterns. During the year, the fewest number of fishes per unit area were present in July, after the initial flooding of the waterways which dispersed the fish communities. Throughout the remainder of the wet season,

Table XV-1. Standing crops of flora and fauna obtained monthly from two temporary waterways in Fahkahatchee Strand, Florida, 1972.

Month	Biological Category	Total Number of Species	Mean Number of Individuals $/m^2$	Mean Biomass $/m^2$ (gm)
Jan.	Fishes	9	187.0	77.6
	Other vertebrates			
	Macrocrustaceans	1	35.5	75.3
	Aquatic plants	4		3,810.1
Feb.	Fishes	7	24.5	26.0
	Other vertebrates	1	2.5	2.9
	Macrocrustaceans	1	23.5	72.6
	Aquatic plants	4		4,226.2
Mar.	Fishes	8	239.0	101.1
	Other vertebrates	2	1.5	0.8
	Macrocrustaceans	2	32.0	113.6
	Aquatic plants	6		3,495.5
Apr.	Fishes	8	575.0	172.8
	Other vertebrates			
	Macrocrustaceans	2	14.0	54.2
	Aquatic plants	4		4,284.2
May	Sampling sites dried-up			
June	Sampling sites dried-up			
July	Fishes	2	3.5	1.1
	Other vertebrates	2	24.5	30.3
	Macrocrustaceans	1	86.5	44.2
	Aquatic plants	8		2,664.1
Aug.	Fishes	4	7.5	1.5
	Other vertebrates	2	1.5	1.2
	Macrocrustaceans	1	11.0	6.3
	Aquatic plants	4		2,696.5
Sept.	Fishes	8	18.0	18.4
	Other vertebrates	1	2.5	4.0
	Macrocrustaceans	2	19.0	25.3
	Aquatic plants	3		2,726.5
Oct.	Fishes	6	28.0	10.0
	Other vertebrates	2	2.0	7.1
	Macrocrustaceans	2	18.5	49.3
	Aquatic plants	4		5,420.8

Table XV-1. Standing crops of flora and fauna obtained monthly from two temporary waterways in Fahkahatchee Strand, Florida, 1972. (Continued)

Month	Biological Category	Total Number of Species	Mean Number of Individuals /m^2	Mean Biomass /m^2 (gm)
Nov.	Fishes	4	9.0	3.6
	Other vertebrates	2	2.0	3.0
	Macrocrustaceans	2	13.0	36.9
	Aquatic plants	3		2,640.5
Dec.	Fishes	7	27.5	30.8
	Other vertebrates	1	0.5	1.0
	Macrocrustaceans	2	14.0	40.2
	Aquatic plants	3		2,990.1

there was a steady increase in the size of the community. By January, the water had ceased to flow at the study sites with a gradual drawdown in the water levels during the remainder of the dry season. The progressive loss of surface water concentrated the fishes; they reached their maximum density in April (Table XV-1). The study sites were dry during May and June. Changes in the density of various fishes and other aquatic animals during the wet and dry seasons are tabulated for selected months at the study site (Station A_1) along Janes Scenic Drive (Table XV-2).

The impact of the seasonal fluctuation of fishes on the ecology of the Strand perhaps can be best illustrated by extrapolating the m^2-sample data to the numbers and biomass of fishes per hectare (1 ha = 10,000 $m^2 \cong 2.5$ acres). The standing crops of fishes were equivalent to an average of 132,000 individuals/ha with a biomass of 69,200 gm/ha during the wet season (June through November) and an average of 2,106,000 fishes with a biomass of 817,000 gm/ha during the dry season (December through May).

Other aquatic vertebrates included the peninsular newt (*Diemictylus viridescens*) and various tadpoles (mostly *Rana* spp.). The largest catch of juvenile frogs occurred in July and was composed of recently hatched individuals. During the other months, both the tadpoles and peninsular newt were sporadic in occurrence and were a minor component of the animal populations in the waterways.

The macrocrustaceans in the monthly collections were dominated by crayfish (*Procambarus alleni*) with a sparse occurrence of the freshwater shrimp (*Palaemonetes paludosus*). In fact, crayfish were the major faunal organism in the waterways, exceeding the biomass of fishes in 80.0 percent of the monthly collections (Table XV-1). Mean monthly biomass of crayfish varied from 6.3 to 112.5 gm/m^2, with the peak abundance of 112.7 gm/m^2 in March.

Two aquatic vascular plants, creeping water primrose (*Ludwigia repens*) at Station A_1 and *Diodia virginiana* at Station A_2, dominated the plant communities in the waterways. Eight additional plant species, listed in Table XV-1, occurred

Table XV-2. Seasonal changes in the density of aquatic animals in a temporary waterway adjacent to Janes Scenic Drive, Fahkahatchee Strand, Florida, 1972.

Species	Wet Season Aug. Number/m^2	 Oct. Number/m^2	Dry Season Feb. Number/m^2	 Apr. Number/m^2
Ictalurus natalis		3		1
Fundulus confluentus	2		1	4
Jordanella floridae		1	25	101
Lucania goodei				5
Gambusia affinis	2	34	22	199
Heterandria formosa		1	8	13
Poecilia latipinna	2		1	9
Elassoma evergladei			4	1
Lepomis macrochirus	1			
Lepomis punctatus		8	1	
Diemictylus viridescens			1	
Rana spp.	1			
Palaemonetes paludosus		3		3
Procambarus alleni	8	16	44	25
Total number/m^2	16	66	107	361
Total biomass (gm/m^2)	14.8	89.4	133.7	257.1

in the monthly collections. No relationship was demonstrated between the density of plants and the abundance of fishes or crayfish.

Additional data on percent ash-free dry weight and percent organic nitrogen for animal and plant species occurring in the temporary waterways of Fahkahatchee Strand are provided in Appendix LL. Similar values for a few fishes from canals adjacent to the strand are included in the same appendix.

Canal Habitats

The standing crops of fishes by number and by biomass (wet weight) in the two GAC and Tamiami canals were strikingly dissimilar (Tables XV-3 and 4). In the Tamiami Canal, 34,999 fishes (38.9 individuals/m^2) with a total biomass of 153.6 kg (170.7 gm/m^2) were recovered in the tidal canal. The fishes from the sampling site in the GAC Canal totalled 3,559 individuals (1.8 fish/m^2) with a biomass of 12.8 kg (6.6 gm/m^2). Thus, on a m^2-basis, the number of individuals and biomass of fishes in the Tamiami Canal exceeded the estimate from the GAC Canal by 95.4 percent and 96.1 percent, respectively.

Dissimilar species and biomass compositions were demonstrated between the canals. The dominant fishes in the Tamiami Canal were mosquitofish and flagfish which represented, respectively, 59.6 percent and 25.8 percent of all the fishes (Table XV-4). Dominance was reversed when examining the biomass composition. By weight, the Florida gar comprised 80.5 percent of the total biomass, but represented only 0.5 percent of the total number of fishes. Conversely, the biomass of mosquitofish constituted only 2.3 percent of the total catch.

Table XV-3. Standing crop of fishes in the most eastern GAC Canal, Fahkahatchee Strand, Florida, February, 1972. Surface area of the sampling site was 1,950 m^2.

Species	Number	Size Range (mm)	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m^2 (gm)
Lepisosteus platyrhincus	1	472	0.03	625.0	4.87	0.320
Notemigonus crysoleucas	7	62-104	0.20	41.7	0.32	0.021
Notropis maculatus	17	32-56	0.48	14.5	0.11	0.007
Erimyzon sucetta	61	33-110	1.71	58.0	0.45	0.030
Ictalurus natalis	5	60-83	0.14	16.7	0.13	0.008
Fundulus chrysotus	1	54	0.03	1.8	0.01	0.001
Fundulus seminolis	6	119-130	0.17	102.1	0.80	0.052
Jordanella floridae	8	25-42	0.22	7.0	0.05	0.004
Lucania goodei	2,080	18-37	58.44	710.5	5.54	0.364
Gambusia affinis	56	18-41	1.57	17.0	0.13	0.009
Heterandria formosa	128	16-23	3.60	16.5	0.13	0.008
Poecilia latipinna	5	17-38	0.14	5.0	0.04	0.002
Labidesthes sicculus	5	76-100	0.14	6.5	0.05	0.003
Elassoma evergladei	10	24-28	0.28	2.0	0.02	0.001
Enneacanthus gloriosus	52	46-52	1.46	114.0	0.89	0.058
Lepomis gulosus	50	58-171	1.40	1,188.5	9.27	0.609
Lepomis macrochirus	24	105-221	0.67	1,510.5	11.78	0.775
Lepomis marginatus	4	42-60	0.11	10.0	0.08	0.005
Lepomis microlophus	371	45-120	10.42	1,923.7	15.00	0.986
Lepomis punctatus	649	44-191	18.24	5,023.9	39.18	2.576
Micropterus salmoides	13	43-309	0.36	1,419.9	11.07	0.728
Etheostoma fusiforme	6	31-49	0.17	6.0	0.05	0.003
Total	3,559			12,820.8		6.570

The majority of fishes in the GAC Canal, in decreasing order of abundance, were bluefin killifish, spotted sunfish, and redear sunfish (*Lepomis microlophus*). These three species comprised 58.4 percent, 18.2 percent, and 10.4 percent of the actual catch. An examination of the biomass composition, perhaps predictably, demonstrated a somewhat different viewpoint. By weight, the sunfishes (Centrarchidae) dominated the fish community in this habitat (Table XV-3). The most abundant fishes by biomass were spotted sunfish (39.2 percent), redear sunfish (15.0 percent), bluegill (11.8 percent), and largemouth bass (*Micropterus salmoides*) (11.9 percent), while the bluefin killifish represented only 5.5 percent of the total catch.

Differences in the age and in the physical and biological characteristics of the two canals undoubtedly contributed to many of the dissimilarities in the fish communities. The eastern branch of the GAC Canal (Figure XV-1) was completed in 1971, whereas the Tamiami Canal was constructed in the 1920's. Thus, these two waterways may be thought of as "new" and "old" canals. The new canal featured a shoreline consisting of abrupt limestone outcropping with a shallow mud bottom overlaying a limestone bed. Thick stands of rooted vascular aquatics, mainly *Naias guadalupensis*, carpeted the bottom. In contrast, the old canal (Tamiami) possessed a mud shoreline on the side adjacent to U. S. Hwy 41, with a boggy cattail (*Typha*) marsh on the other. The soft mud bottom was covered with scattered stands of filamentous algae, particularly near the shallow shorelines. Both waterways maintained about the same mean depth.

Table XV-4. Standing crop of fishes in the Tamiami Canal at Big Cypress Bend, Florida, March, 1972. Surface area of the sampling site was 900 m^2.

Species	Number	Size Range (mm)	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m^2 (gm)
Lepisosteus platyrhincus	189	235-631	0.54	123,649.7	80.48	137.389
Notemigonus crysoleucas	2	62-106	<0.01	9.0	<0.01	0.010
Notropis maculatus	2	48-53	<0.01	1.7	<0.01	0.002
Erimyzon sucetta	1	74	<0.01	3.5	<0.01	0.004
Ictalurus natalis	1	70	<0.01	3.2	<0.01	0.004
Strongylura notata	1	288	<0.01	35.5	0.02	0.039
Cyprinodon variegatus	2	22-28	<0.01	1.0	<0.01	0.001
Fundulus chrysotus	1	23	<0.01	0.3	<0.01	<0.001
Fundulus confluentus	1,156	22-41	3.30	671.2	0.44	0.746
Jordanella floridae	9,020	19-36	25.77	2,880.4	1.87	3.200
Lucania goodei	278	20-35	0.79	86.3	0.06	0.096
Lucania parva	974	20-36	2.79	250.1	0.16	0.278
Gambusia affinis	20,868	15-39	59.62	3,550.7	2.31	3.945
Heterandria formosa	253	12-21	0.72	19.9	<0.01	0.022
Poecilia latipinna	1,539	18-35	4.40	700.3	0.46	0.778
Menidia beryllina	1	42	<0.01	0.5	<0.01	<0.001
Centropomus undecimalis	4	330-641	0.01	5,289.0	3.44	5.877
Elassoma evergladei	4	19-28	0.01	1.5	<0.01	0.002
Lepomis gulosus	46	29-62	0.13	1,241.0	0.81	1.379
Lepomis macrochirus	75	29-115	0.21	161.0	0.10	0.179
Lepomis marginatus	12	45-71	0.03	36.0	0.02	0.040
Lepomis microlophus	17	89-180	0.05	508.0	0.33	0.564
Lepomis punctatus	515	32-145	1.47	1,101.0	0.72	1.223
Micropterus salmoides	7	238-376	0.02	3,171.0	2.06	3.523
Diapterus plumieri	11	92-291	0.03	2,694.0	1.75	2.993
Mugil cephalus	17	315-383	0.05	7,573.8	4.93	8.415
Microgobius gulosus	2	47-63	<0.01	2.2	<0.01	0.002
Trinectes maculatus	1	30	<0.01	1.5	<0.01	0.002
Total	34,999			153,643.3		170.715

Another major difference in the two canals was attributed to the water type. The source of fresh water in the GAC (new) Canal was runoff (primarily during the wet season) and by the discharge of ground water (throughout the year). Thus, flowing water, although reduced at the time of sampling on February 28, was present throughout the year.

The Tamiami Canal in contrast lies in an east-west direction parallel to U. S. Hwy 41, and perpendicular to Fahkahatchee Strand. Ground water, surface water, and tidal waters mix in the canal and ultimately flow by way of numerous bridges to the saltmarshes and by a north-south interceptor canal near S.R. 29 to the estuary below. Waters in the canal are generally sluggish and have high salinity variations depending upon the hydroperiod and tidal cycle. On March 2, the salinity at the time of sampling near Big Cypress Bend was 3.0 ppt. The salinity at the sampling sites in the Tamiami Canal steadily increased during the dry season, and in 1972, reached a high of 27.7 ppt in May. Following the onset of the rainy season late in June, freshwater conditions returned to this waterway for the remainder of the year.

The main dissimilarities between the GAC and Tamiami Canals were attributed to the time of construction and to annual, as well as to semi-diurnal, fluctuations in the salinity levels of Tamiami Canal. Both of these factors affected the abundance and species composition of the fish communities. Twenty-three species of freshwater fishes were identified from the GAC Canal, whereas 21 freshwater species, plus an additional 6 estuarine species, were taken in the Tamiami Canal. Species of estuarine fishes included snook, striped mullet (Mugil cephalus), striped mojarra (Diapterus plumieri), sheepshead minnow (Cyprinodon variegatus), clown goby (Microgobius gulosus), tidewater silverside (Menidia beryllina), and hog choker (Trinectes maculatus) (Table XV-4). By weight, these saltwater fishes represented 10.2 percent of the total catch.

The given canal data represents the only reported information on standing crops of fishes from the Tamiami and GAC Canals. The fish communities of other Everglades canals (Miami Canal and South New River Canal) were investigated by Clugston (1962) during the dry season, eight months after the occurrence of a summer fish kill. Clugston reported biomass estimates of 19.4, 37.0 and 104.5 gm/m^2 from three canal sites. His mean biomass value of 53.6 gm/m^2 was eight times greater than the biomass of fishes from the GAC Canal and three times less than the biomass of fishes in the Tamiami Canal. Near Miami, the composition of fishes in the Tamiami Canal, based on angling and net collections (Hunt, 1953), was similar to the fish species, excluding the saltwater fishes, in the Tamiami Canal at Big Cypress Bend.

The two major piscivores in the man-made canal systems of south Florida are Florida gar and bowfin (Amia calva). Clugston (1962) reported that bowfin represented 96.4 (18.7 gm/m^2) and 97.2 percent (101.6 gm/m^2) of the biomass composition at two sites in the Miami Canal, while the Florida gar constituted 91.4 percent (33.8 gm/m^2) of total biomass at a single site in South New River Canal. O'Connell (1958), as cited by Hunt (1960), used electro-fishing gear during a rough fish removal program in 12.8 km (8 mile) section of the Tamiami Canal. By weight, Florida gar and bowfin populations represented approximately 20.0 and 60.0 gm/m^2, respectively, but the Florida gar occurred in greater numbers than the bowfin. In the present study, the biomass of Florida gar in the Tamiami Canal at Big Cypress Bend was 137.4 gm/m^2 which greatly exceeded the estimates from other canals in South Florida.

Review of Table XV-4 will indicate that an overwhelming portion of the total reported standing crop biomass is comprised of piscivores. At first glance, this may seem to be an impossible situation if the classical concept of a trophic pyramid is invisioned. However, Tamiami Canal is not a closed system. The reported estimates of standing crop (biomass) fail to take into account recruitment to the system of forage animals from adjoining marshlands and waterways. Also to be considered is the role of the macroinvertebrate community in the diet of the predators. Finally, in light that the data represents only one sampling period of the year, the reported standing crop biomass could be a reflection of a seasonal concentration of predators in the canal.

Strand Lake Habitat

The fish population of a natural lake (Station D or Ballard's Lake) was sampled in early April (Figure XV-1). Ballard's Lake is a shallow depression with a surface area of 4,069 m^2 and a mean water depth of 1.2 m at the time of sampling. Floating aquatic plants, mainly water lettuce (Pistia stratiotes) and duckweed (*Lemna perpusilla*) intermixed with small floating islands (1.0 to 2.0 m in diameter) covered approximately 70.0 percent of the water surface. Stands of giant cutgrass (*Zizaniopsis miliacea*) and button bush (*Cephalanthus occidentalis*) characterized the boggy shoreline. The main source of water for this lake was surface runoff. Estimates of fish populations were conservative because of the dense stands of floating aquatics, which hampered the recovery of fishes.

The standing crop of fishes in Ballard's Lake consisted of 2,483 individuals (0.6 fish/m^2) with a total biomass of 57.4 kg (14.1 gm/m^2) distributed among 16 species (Table XV-5). Mosquitofish and yellow bullhead (*Ictalurus natalis*) were the most abundant species, comprising 57.7 percent and 33.1 percent, respectively, of the total number. The biomass composition was dominated by yellow bullhead (58.7 percent), Florida gar (24.1 percent), bowfin (7.4 percent), and brown bullhead (*Ictalurus nebulosus*) 5.3 percent).

Table XV-5. Standing crops of fishes and amphibians from a natural lake in Fahkahatchee Strand, Florida, April, 1973. Surface area of the sampling site was 4,069 m^2.

	Number	Size Range (mm)	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m^2 (gm)
Fishes						
Amia calva	4	460-505	0.16	4,268.0	7.42	1.049
Lepisosteus platyrhincus	24	198-642	0.97	13,860.6	24.12	3.406
Notemigonus crysoleucas	12	97-134	0.48	196.9	0.34	0.048
Ictalurus natalis	823	69-332	33.14	33,748.4	58.74	8.294
Ictalurus nebulosus	74	89-348	3.00	3,024.7	5.26	0.743
Fundulus chrysotus	1	35	0.04	0.4	<0.01	<0.001
Fundulus confluentus	9	35-52	0.36	13.4	0.02	0.003
Jordanella floridae	5	26-47	0.20	5.9	0.01	0.001
Lucania goodei	7	24-34	0.28	2.5	<0.01	<0.001
Gambusia affinis	1,432	14-46	57.67	328.6	0.57	0.081
Heterandria formosa	5	16-27	0.20	0.7	<0.01	<0.001
Poecilia latipinna	5	33-60	0.20	12.2	0.02	0.003
Lepomis gulosus	24	90-181	0.97	1,128.0	1.96	0.277
Lepomis macrochirus	29	71-148	1.17	579.5	1.01	0.142
Lepomis microlophus	1	103	0.04	22.5	0.04	0.006
Lepomis punctatus	28	50-103	1.13	259.8	0.45	0.064
Subtotal	2,483			57,452.1		14.119
Amphibians						
Amphiuma means	1	529	4.35	435.2	6.96	0.107
Siren lacertina	22	208-630	95.65	5,819.2	93.04	1.430
Subtotal	23			6,254.5		1.537
Total	2,506			63,706.6		15.656

Two large salamanders, greater siren (*Siren lacertina*) and amphiuma (*Amphiuma means*), were present in the lake (Table XV-5). This was the only habitat in which these two species were encountered during the year. Although only 23 individuals were caught, their total biomass of 6.2 kg represented 1.5 gm/m^2. When combined with the fish data, the standing crops of aquatic vertebrates in Ballard's Lake by weight represented 15.7 gm/m^2. Fishes and amphibians served as a potential food supply for a reproducing population of alligators (*Alligator mississippensis*) inhabiting the lake.

Bay Habitats

The standing crops of estuarine fishes (combined total catch estimate) in Fahka Union Bay consisted of 686 fishes (0.1 fish/m^2) with a biomass of 33.8 kg (5.2 gm/m^2), while the combined estimate in Fahkahatchee Bay totalled 1,958 individuals (0.4 fish/m^2) with a biomass of 25.9 kg (5.3 gm/m^2) (Tables XV-6 and 7). On an areal basis, the biomass of fishes in Fahkahatchee Bay exceeded the estimates from Fahka Union Bay at two of three sampling sites. However, the mean estimate of biomass from both bays was essentially identical.

A single biomass value, unless accompanied by analysis of the various species of the community is often misleading. In these two bays, the species compositions were strikingly different. In Fahka Union Bay, over half the fishes in the total catch were mojarras (*Eucinostomus* spp.) with lesser numbers of yellowfin menhaden (*Brevoortia smithi*) (15.2 percent), code goby (*Gobiosoma robustum*) (4.4 percent), and Gulf pipefish (*Syngnathus scovelli*) (3.8 percent), plus an assortment of other fishes (Table XV-6). In Fahkahatchee Bay, the dominant species of fishes were composed of pinfish (*Lagodon rhomboides*) (55.8 percent), silver perch (*Bairdiella chysura*) (12.8 percent), majorras (12.3 percent), code goby (5.2 percent), and Gulf pipefish (2.5 percent). Also, more species of fishes were recorded from Fahkahatchee Bay (33) than from Fahka Union Bay (26) during this survey.

Compositions by biomass were quite dissimilar between the bays. Over half of the total biomass in Fahka Union Bay was dominated by the Atlantic stingray (*Dasyatis sabina*) which represented only eight individuals. In Fahkahatchee Bay, the major component of the biomass (50.0 percent) was composed of pinfish, numbering 1,092 individuals. Other major components of the biomass in Fahka Union Bay were ladyfish (*Elops saurus*) (7.7 percent), striped mullet, and sea catfish (*Arius felis*). The last two species each represented 7.4 percent of the total biomass. In Fahkahatchee Bay, the abundant pinfish were followed by Atlantic stingray (19.3 percent), striped mullet (8.4 percent), and silver perch (4.6 percent). In addition, popular sport and food fishes, such as snook, spotted seatrout, and gray or mangrove snapper were represented in the sample catches from both bays (Tables XV-5 and 6).

Initially, we had intended to analyze the data from the enclosure net by the DeLury regression method (Lagler, 1956). This technique provides an estimate of the size of the population based on the catch per unit-of-effort. However, DeLury's method is only considered valid if the following three conditions are met: closed population, constant unit-of-effort, and equal catchability of fishes. Although we fulfilled two of the conditions, the data were not amenable to DeLury's method, since some fish species, such as Atlantic stingray and striped mullet, exhibited a differential response to the gear. Also, at two study sites, the catch per seine haul steadily declined, as expected, during the first three or four tows, but suddenly increased during the last couple of

Table XV-6. Standing crops of fishes from three sites in Fahka Union Bay, Florida, September, 1972.

Species	Station E Area - 1,840 m²		Station F Area - 2,788 m²		Station G Area - 1,840 m²		Combined Estimate Total Area - 6,468 m²				
	Number	Biomass (gm)	Number	Biomass (gm)	Number	Biomass (gm)	Number	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m² (gm)
Dasyatis sabina	1	840.4	2	1,027.4	5	17,293.7	8	1.17	19,161.5	56.63	2.962
Elops saurus	2	421.4	8	2,073.8	1	109.0	11	1.60	2,604.2	7.70	0.403
Brevoortia smithi					104	679.8	104	15.16	679.8	2.01	0.105
Anchoa hepsetus			30	82.4			30	4.37	82.4	0.24	0.013
Synodus foetens			3	3.9	3	44.1	6	0.87	48.0	0.14	0.007
Arius felis			10	2,390.7	1	95.7	11	1.60	2,486.4	7.35	0.384
Hyporhamphus unifasciatus			2	14.3			2	0.29	14.3	0.04	0.002
Syngnathus scovelli			6	0.8	20	5.0	26	3.79	5.8	0.02	0.001
Centropomus undecimalis					4	1,368.5	4	0.58	1,568.5	4.64	0.242
Lutjanus griseus					4	1,076.3	4	0.58	1,076.3	3.18	0.166
Diapterus plumieri					4	803.9	4	0.58	803.9	2.38	0.124
Eucinostomus argenteus					49	196.9	49	7.14	196.9	0.58	0.030
Eucinostomus gula	2	11.9			179	992.6	181	26.38	1,004.5	2.97	0.155
Eucinostomus spp.			173	504.5	2	1.5	175	25.51	506.0	1.49	0.078
Archosargus probatocephalus					3	634.6	3	0.44	634.6	1.88	0.098
Lagodon rhomboides					13	139.8	13	1.89	139.8	0.41	0.022
Bairdiella chrysura			4	0.8			4	0.58	0.8	<0.01	<0.001
Cynoscion nebulosus			1	0.7			1	0.14	0.7	<0.01	<0.001
Mugil cephalus					4	2,518.6	4	0.58	2,518.6	7.44	0.389
Gobiosoma robustum			32	5.1			32	4.66	5.1	<0.01	<0.001
Scomberomorus maculatus			1	175.4			1	0.14	175.4	0.52	0.027
Prionotus sp.			1	0.7			1	0.14	0.7	<0.01	<0.001
Paralichthys albigutta					1	75.8	1	0.14	75.8	0.22	0.012
Achirus lineatus	3	1.7	2	0.2	1	4.3	6	0.87	6.2	0.02	0.001
Symphurus plagiusa			4	3.0			4	0.58	3.0	<0.01	<0.001
Sphoeroides nephelus					1	37.0	1	0.14	37.0	0.11	0.006
Total	8	1,275.4	279	6.283.7	399	26,277.1	686		33,836.2		
Mean biomass (gm/m²)		0.7		2.2		14.3					5.2

Table XV-7. Standing crops of fishes from three sites in Fahkahatchee Bay, Florida, September, 1972.

Species	Station H Area - 1,208 m²		Station I Area - 1,717 m²		Station J Area - 1,947 m²		Combined Estimate Total Area - 4,868 m²				
	Number	Biomass (gm)	Number	Biomass (gm)	Number	Biomass (gm)	Number	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m² (gm)
Dasyatis sabina					1	5,000.0[a]	1	0.05	5,000.0[a]	19.30	1.027
Myrophis punctatus					2	7.9	2	0.10	7.9	0.03	0.002
Brevoortia smithi	2	15.5					2	0.10	15.5	0.05	0.003
Harengula pensacolae	1	5.2					1	0.05	5.2	0.02	0.001
Opisthonema oglinum	4	15.9	6	35.0			10	0.51	50.9	0.19	0.010
Anchoa mitchilli			2	0.5	3	2.4	5	0.25	2.9	0.01	0.001
Synodus foetens					12	96.2	12	0.61	96.2	0.37	0.020
Opsanus beta			1	392.9	39	194.6	40	2.04	587.5	2.26	0.121
Hyporhamphus unifasciatus					1	7.1	1	0.05	7.1	0.02	0.001
Strongylura notata					2	21.6	2	0.10	21.6	0.08	0.004
Strongylura timucu					2	92.3	2	0.10	92.3	0.35	0.019
Syngnathus scovelli	18	6.3			31	11.5	49	2.50	17.8	0.06	0.004
Centropomus undecimalis					1	494.0	1	0.05	494.0	1.90	0.010
Oligoplites saurus					1	1.2	1	0.05	1.2	<0.01	<0.001
Lutjanus griseus	1	285.6	2	332.0	3	39.5	6	0.30	657.1	2.53	0.135
Diapterus plumieri					4	464.8	4	0.20	464.8	1.79	0.094
Eucinostomus argenteus	12	42.0			13	30.6	25	1.28	72.6	0.28	0.015
Eucinostomus gula	54	240.0	3	16.8	126	558.9	183	9.34	815.7	3.14	0.168
Eucinostomus spp.	4	0.2			29	24.0	33	1.68	24.2	0.09	0.005
Orthopristis chrysoptera	18	323.5	3	15.2			21	1.07	338.7	1.30	0.070
Archosargus probatocephalus	10	45.9			8	66.8	18	0.92	112.7	0.43	0.023
Lagodon rhomboides	781	9,336.9	76	1,415.4	235	2,197.4	1,092	55.77	12,949.7	49.99	2.660
Bairdiella chrysura	83	760.2	2	20.6	166	418.4	251	12.82	1,199.2	4.62	0.246
Cynoscion nebulosus	10	196.3			12	230.9	22	1.12	427.2	1.64	0.088
Mugil cephalus					3	2,184.0	3	0.15	2,184.0	8.43	0.447
Chasmodes saburrae					4	1.8	4	0.20	1.8	<0.01	<0.001
Gobiosoma bosci					1	0.4	1	0.05	0.4	<0.01	<0.001
Gobiosoma robustum	1	0.3	12	3.6	89	18.0	102	5.21	21.9	0.08	0.004
Microgobius gulosus	1	0.1			5	1.2	6	0.30	1.3	<0.01	<0.01
Etropus crossotus					2	7.8	2	0.10	7.8	0.03	0.002
Achirus lineatus	1	0.3			1	0.9	2	0.10	1.2	<0.01	<0.001
Symphurus plagiusa					52	43.3	52	2.66	43.3	0.16	0.009
Sphoeroides nephelus			2	177.3			2	0.10	177.3	0.68	0.036
Total	1,001	11,274.2	109	2,409.3	848	12,217.5	1,958		25,901.0		
Mean biomass (gm/m²)		9.3		1.4		6.3					5.3

[a] Estimated weight, observed only.

tows. This reversal in the catch was attributed in part to the earlier removal of large quantities of vegetation which initially hampered the seining operation. Thus, the standing crop of fishes were analyzed on the basis of the actual total catch.

The distribution of bottom vegetation at several study sites influenced the composition of fishes. In Fahka Union Bay, the benthic vegetation was composed of sparse stands of Diplanthera wrightii at Station F and a moderate amount of red algae, such as Gracillaria spp., at Station G, while Station E was devoid of vegetation. Benthic vegetation was more abundant in Fahkahatchee Bay. Mixed stands of Diplanthera - Thalassia beds and various algae were prominent at Station H, and thick stands of marine algae covered the bottom at Station J, while moderate amounts of algae were present at Station I. The largest number of benthic fishes, such as pinfish, silver perch, and pig fish (Orthopristis chrysoptera) were taken in the Diplanthera - Thalassia beds at Station H. Other fishes such as ladyfish, anchovies (Anchoa spp.), needlefishes (Strongylura spp.), snook, and clupeids are pelagic species that feed primarily in the water column, and thus, bottom types generally have little effect on their distribution.

In summary, the fish communities differed between the two bays in several respects: (1) there were four times as many fishes per unit area in Fahkahatchee Bay than in Fahka Union Bay even though the mean biomass totals were similar; (2) a greater number of species were present in Fahkahatchee Bay as opposed to the other bay; and (3) the four dominant species by weight contributed over 70.0 percent of the total biomass in each bay. However, in Fahkahatchee Bay, this biomass was distributed among 1,347 individuals, while in Fahka Union Bay, a similar percentage of the biomass was attributed to 34 individuals, mostly adults.

Tidal Stream Habitat

The standing crop of fishes in a tidal stream (Station K) contiguous with north Fahkahatchee Bay was composed of 27 species. Numerically, the mojarras (Eucinostomus gula and E. argenteus) were dominant species representing 81.0 percent of the total fish communities. Other abundant species were bay anchovy (Anchoa mitchilli) (9.0 percent), juvenile sheepshead (Archosargus probatocephalus) (4.7 percent), pinfish (1.4 percent), striped mojarra (Diapterus plumieri) (1.1 percent), and striped mullet (1.1 percent).

The biomass composition was predominantly striped mullet and mojarras (Eucinostomus spp.) which represented 42.0 and 40.2 percent, respectively, of the total catch. Other major representatives in decreasing order by weight were sheepshead, striped mojarra, sea catfish, redfin needlefish (Strongylura notata), and timucu (S. timucu) (Table XV-8).

Red mangrove trees lined the shoreline of this natural stream while the surrounding terrain was densely forested. The area adjacent to the stream was flooded during periods of high tides. It was not possible to obtain an estimate of the area of inundation from aerial photographs because of the thick canopy.

The standing crop of fishes from the tidal stream represented 98.9 gm/m^2 (Table XV-8). This value was an overestimate and not comparable with other habitats, since an unknown portion of the fish community had moved from the flooded lowlands to the stream in ebbing waters. Nevertheless, the fishes

Table XV-8. Standing crop of fishes from a tidal stream in north Fahkahatchee Bay, October, 1972. Surface area of the sampling site was 734 m^2 on a low ebb tide.

Species	Number	Size Range (mm)	Species Composition (%)	Biomass (gm)	Biomass Composition (%)	Biomass/m^2 (gm)
Myrophis punctatus	1	278	0.02	10.5	0.02	0.014
Anchoa mitchilli	473	14-65	9.01	332.4	0.50	0.453
Arius felis	2	337-370	0.04	780.0	1.18	1.063
Opsanus beta	2	68-120	0.04	31.1	0.05	0.042
Strongylura marina	1	380	0.02	75.2	0.11	0.102
Strongylura notata	7	195-410	0.13	729.4	1.11	0.994
Strongylura timucu	20	118-431	0.38	528.6	0.80	0.720
Cyprinodon variegatus	2	15-20	0.04	1.0	<0.01	0.001
Lucania parva	1	26	0.02	0.9	<0.01	0.001
Centropomus undecimalis	6	66-138	0.11	31.9	0.05	0.043
Caranx hippos	1	62	0.02	4.2	<0.01	0.006
Oligoplites saurus	13	53-91	0.25	27.3	0.04	0.037
Lutjanus griseus	7	62-184	0.13	365.3	0.55	0.498
Diapterus plumieri	58	50-323	1.10	1,732.5	2.63	2.360
Eucinostomus argenteus	423	28-97	8.06	1,782.0	2.70	2.428
Eucinostomus gula	3,544	45-99	67.52	24,705.4	37.49	33.658
Eucinostomus spp.	282	13-39	5.37	24.4	0.04	0.033
Archosargus probatocephalus	246	62-380	4.69	5,716.7	8.68	7.788
Lagodon rhomboides	73	68-91	1.39	615.5	0.93	0.838
Cynoscion nebulosus	19	77-212	0.36	532.6	0.81	0.726
Menticirrus littoralis	1	91	0.02	5.1	0.08	0.007
Scianops ocellata	1	249	0.02	150.0	0.23	0.204
Mugil cephalus	56	155-503	1.07	27,683.4	42.01	37.716
Bathygobius soporator	2	76-101	0.04	21.5	0.03	0.029
Gobionellas shufeldti	3	40-57	0.06	1.8	<0.01	0.002
Gobiosoma robustum	1	20	0.02	0.5	<0.01	0.001
Lophogobius cyprinoides	1	49	0.02	1.0	<0.01	0.001
Microgobius gulosus	3	21-27	0.06	1.2	<0.01	0.002
Total	5,249			65,891.4		89.770

recovered in this survey indicated that tidal streams serve as an important habitat for numerous sport and commercial species, such as spotted seatrout, gray snapper, snook, crevalle jack (*Caranx hippos*), sheepshead, striped mullet, pinfish, and striped mojarra.

Discussion

The temporary waterways (shallow borrow canals) that served as study sites in Fahkahatchee Strand were analogous in many respects to other freshwater habitats, such as prairie ponds, sloughs, swamp depressions, marsh areas, lakes, and alligator ponds. Many of these upland aquatic habitats were initially inundated during the rainy season. The accumulation of surface runoff in the early summer serves as a mechanism of dispersal, opening up new feeding and spawning areas for poecilids, cyprinodonts, centrarchids, and other fishes. With the commencement of the dry season in late fall, the surface waters gradually recede and the fishes retreat from the shallow margins of the wetlands and collect in the remaining pockets of water. Permanent aquatic areas, such as deeper ponds, lakes, and canals that remain inundated throughout the dry season, function as reservoirs for the fish populations of the Strand. Thus, the distribution and abundance of the fishes were directly related to the cyclic nature of the hydroperiod.

Food chain interrelationships of freshwater fishes play an important role in the ecology of the Strand. Fishes incorporate both plant and animal material into tissue and as a group, serve as an intermediate link between primary producers (plants) and the tertiary consumers (higher predators). Sailfin molly and flagfish are herbivores which feed upon green and bluegreen algae, diatoms, vascular plant material, and detritus with lesser amounts of rotifers, protozoans and ostracods (Hunt, 1953 and Odum and Heald, 1972). Omnivorous fishes, such as mosquitofish, least killifish, and bluefin killifish, feed on a mixed diet of algae, some phytoplankton, copepods, oligocheates, rotifers, mites, amphipods, snails, and other invertebrates including immature insects. Carnivorous fishes, which were generally more numerous in the permanent aquatic habitats (Strand lakes and adjacent canals), consisted of spotted sunfish, redear sunfish, warmouth, largemouth bass, and Florida gar. Forage fishes and generally the larger invertebrates (mayfly and dragonfly nymphs, crayfish, ostracods, snails and freshwater shrimp) form the bulk of their diet (Hunt, 1953).

Fishes and macrocrustaceans are important food items in the diet of other vertebrate animals such as birds, raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), turtles, snakes, and alligators. Numerous wading birds, e.g., great blue heron (*Ardea herodius*), little blue heron (*Florida caerula*), wood stork (*Mycteria americana*), American egret (*Casmerodius albus*), white ibis (*Eudocimus albus*), and others, were often observed foraging in shallow waters for fishes and crayfish. The winter nesting season of wood stork, herons, ibises, and egrets occurs concurrently with the lowered water levels and the resultant concentration of forage organisms during the dry season. The breeding success of many of these birds is related to the availability and abundance of an adequate piscivorous diet. For example, a nesting colony of wood stork, composed of 12,000 adults and their altricial young, consumed more than 1.2 million kg of small forage fishes during the two months of the breeding season (Kahl, 1962, 1964 quoted from Odum, 1971).

Alligators subsist on a variable diet that is either directly or indirectly dependent upon the aquatic environment. Immature alligators (less than 152.5 cm in length) from an Everglades canal fed mainly on invertebrates (crayfish, snails, and insects) and lesser quantities of fishes (Focarty and Albury, 1967). Larger alligators prefer vertebrate animals, as McIlhenny (1934) found gar, herons, egrets, and snakes in the stomachs of alligators collected near bird rookeries on Avery Island, Louisiana. Species of fishes in alligators' diets reported by these authors and others included flagfish, mosquitofish, largemouth bass, other sunfishes (*Lepomis* spp.), seminole killifish (*Fundulus seminolis*), bowfin, and gar.

RELATIVE ABUNDANCE OF ESTUARINE FISHES

Habitats, Sampling Gear, and Procedures

Twenty-two fish collections were obtained monthly at 14 regular stations from January through December, 1972, in the estuarine waters of the Ten Thousand

Islands (Figure XV-2). As a measure of relative abundance, these collections comprised the monthly standard unit-of-effort. Sampling was usually conducted during the first week of each month at the time of the new moon when maximum tides prevailed.

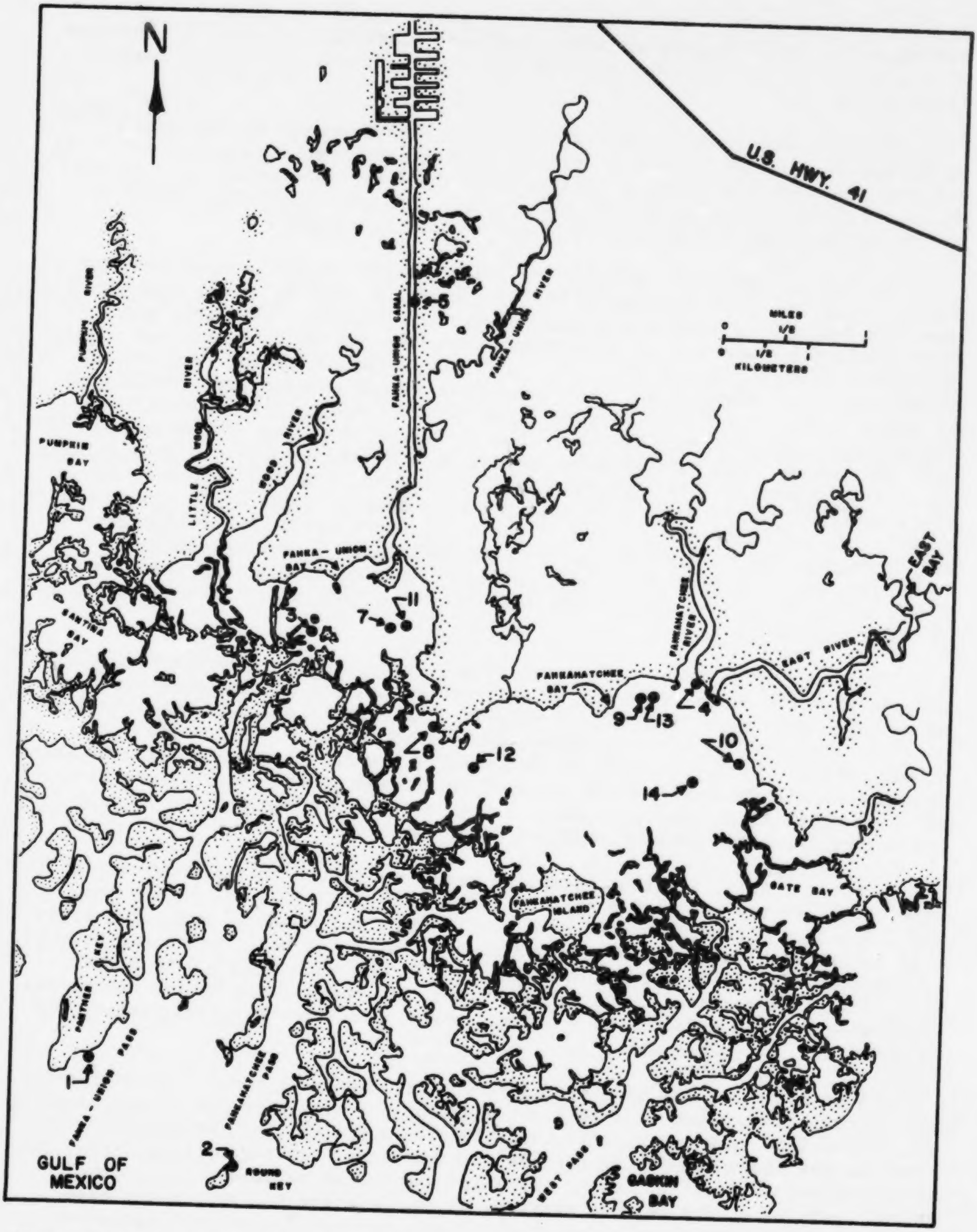
Several ecological classifications have been proposed for estuarine environments, many of which are only appropriate for specific areas. To compare zones, the estuary was divided into three somewhat arbitrary physical divisions (lower reaches, middle reaches, and upper reaches) which follow a modification of the terminology proposed by Carriker (1967).

In the Ten Thousand Islands, the lower reaches of the estuary referred primarily to the outer beaches in the surf zone, as well as to the shallow nearshore waters and numerous inlets between the islands. This zone was characterized by sand and shell bottoms, pronounced tidal currents, and salinities generally above 30.0 ppt. Benthic vegetation varied from none to dense stands of marine algae. Middle reaches of the estuary were represented by bays, channels, and tidal streams with thick stands of red mangrove (*Rhizophora mangle*) lining the shorelines. Typical features of this zone were soft mud and mud-sand bottoms with varying amounts of marine algae (*Gracillaria* spp.) and *Thalassia* - *Diplanthera* beds. Upper reaches of the estuary were characterized by soft muddy bottoms, currents ranging from slow to rapid, and usually low salinities in a range of 0.1 to 10.0 ppt during the rainy season. Bottom vegetation, if present, was usually restricted to sparse stands of filamentous green algae. This zone included streams, canals, and marsh lands that receive freshwater runoff from the uplands but nevertheless were subjected to tidal influences.

The estuary in the Ten Thousand Islands is a rather narrow belt, which extends from the ocean front to the salt marshes in the extreme upper reaches, an average distance of 8.0 km (5.0 miles). The upper reaches are delimited by man-made barriers, in most instances, such as roadbeds (U. S. Hwy 41) and stream weirs. The major source of fresh water enters the estuary through either drainage canals (Tamiami and GAC Canals) or altered stream beds (Barron River and Blackwater River Canals). Natural freshwater runoff enters the estuary from the wet prairies and marshes south of U. S. Hwy 41.

At the regular stations, sampling gear consisted of two bag seines, an otter trawl or try net, and a surface trawl. One bag seine was 30.5 m long and 1.8 m deep with 0.64 cm-bar mesh, while the other was 15.2 m X 1.2 m with 0.64 cm-bar mesh in the wings and 0.3 cm-bar mesh in the bag. The otter trawl, constructed of 2.54 cm-bar mesh netting, was 3.05 m wide with a 0.64 cm-bar mesh liner in the codend. The surface trawl, which was towed by two boats, was 6.5 m wide and 0.8 m deep with a codend length of 6.0 m; the nylon netting was composed of 0.64 cm-bar mesh.

A standardized sampling procedure was followed each month. Surface and otter trawls were towed in a straight line for a 5-minute period at the sampling sites. Surface trawling usually took place on a rising tide, while otter trawling was conducted during periods of high water. At the seining sites, the seine was spread parallel to the shoreline and hauled perpendicular to the shore. Seining at the regular stations on the Gulf beaches and in the bays was conducted during flood tides, while fishes were collected with seines at the two stations in the upper reaches in ebbing waters.


N
U.S. HWY. 41
MILES
0
1/2
1
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1
KILOMETERS
PUMPKIN RIVER
PUMPKIN BAY
LITTLE WOOD RIVER
WOOD RIVER
FAKA-UNION CANAL
FAKA-UNION RIVER
FAKA-UNION BAY
SANTINA BAY
FAKAHATCHEE BAY
FAKAHATCHEE RIVER
EAST RIVER
EAST BAY
GATE BAY
FAKAHATCHEE ISLAND
PANTHER KEY
FAKA-UNION PASS
FAKAHATCHEE PASS
ROUND KEY
WEST PASS
GASKIN BAY
GULF OF MEXICO
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure XV-2. Study area and sampling station in Ten Thousand Islands, Florida. Dots mark the regular seine stations (Numbers 1-6), surface trawl stations (Numbers 7-10), and otter trawl stations (Numbers 11-14).

During 1972, there were a total of 259 regular fish collections consisting of 72 seine hauls, 91 otter trawl tows, and 92 surface trawl tows. Ideally, the monthly standard unit-of-effort was composed of 22 collections represented by single hauls at each of six seine stations and duplicate tows at four otter trawl, as well as at four surface trawl stations. Because of either mechanical problems or damaged gear, five otter trawl and four surface trawl collections were missed during the year.

Study sites were spread throughout the estuary to represent a variety of habitats (Figure XV-2). In the lower reaches, the beach seining sites were at Panther Key (Station 1) and at Round Key (Station 2) facing the open Gulf of Mexico. Seining sites in the middle reaches were located over a soft mud bottom on the south side of a small island in Fahka Union Bay (Station 3) and at the mouth of the Fahkahatchee River in Fahkahatchee Bay over a broken shell substrate (Station 4). In the upper reaches, seining sites consisted of a small embayment at the mouth of a shallow tidal stream with a soft mud bottom on the east side of Fahka Union Canal (Station 5) and at the end of a short canal off Henderson Creek near East Naples (Station 6). Surface trawl sites (Stations 7 through 10) and otter trawl sites (Stations 11 through 14) were in the middle reaches of the estuary in Fahka Union and Fahkahatchee Bays.

Data on fishes were also obtained during preliminary surveys from October through December, 1971, from other studies (standing crops of fishes), and from special collections at other estuarine sites during 1972, such as Tiger Key and Camp Lulu Key in the lower reaches, Gaskin Bay and East Bay in the middle reaches, and numerous brackish water streams in the upper reaches. These random collections were employed to supplement both the ecological data and the list of fish species from the Ten Thousand Islands, but they were not used in calculating the monthly totals from the regular stations.

Results

Relative Abundance by Number

A total of 273,270 individuals, distributed among 96 species and 41 families, were collected by surface trawling, otter trawling, and seining from the 22 regular monthly collections during 1972 (Table XV-9). An additional 38 species, which were collected during the preliminary survey in 1971 and in special studies at other estuarine and freshwater locations, are reported later in the results.

The eight most numerous fish species, in decreasing order of abundance, were bay anchovy, yellowfin menhaden (Brevoortia smithi), scaled sardine (Harengula pensacolae), striped anchovy (Anchoa hepsetus), pinfish (Lagodon rhomboides), silver perch (Bairdiella chrysura), and silver jenny (Eucinostomus gula). The bay anchovy was the dominant fish species in the estuary accounting for 70 percent of the total catch. Excluding the anchovies, the other above species represented 64 percent of the year's total catch (Table XV-10).

In an investigation of the fish fauna of Charlotte Harbor (approximately 120.0 km northwest of our study site in the Ten Thousand Islands), Wang and Raney (1971) reported that the five most abundant species, other than the anchovies, were pinfish, silver perch, silver jenny, pigfish (Orthopristis chrysoptera), and sand seatrout (Cynoscion arenarius). They employed an otter trawl in collecting most of these fishes which accounted for the preponderance

Table XV-9. Distribution of the total catch at the regular stations by species, number, and biomass from Ten Thousand Islands, 1972.

Sampling Gear	Station	Number of Species	Number of Individuals	Biomass (gm)
Seines	1	47	2,729	45,060.9
	2	43	7,983	132,085.0
	3	37	2,497	47,152.2
	4	23	22,309	16,455.1
	5	34	81,037	29,612.9
	6	38	72,339	28,221.4
Subtotal		79	188,894	298,587.5
Surface trawl	7	30	22,282	16,338.5
	8	29	15,721	15,796.8
	9	41	24,487	41,627.4
	10	40	17,192	24,870.7
Subtotal		55	79,682	98,653.4
Otter trawl	11	22	615	1,328.2
	12	29	717	3,325.2
	13	30	1,029	3,679.5
	14	27	2,333	8,769.9
Subtotal		45	4,694	17,102.8
Total		96	273,270	414,343.7

of benthic species comprising 76.1 percent (calculated) of their total catch. They did not adequately sample the pelagic component of the fish fauna since species such as yellowfin menhaden, scaled sardine, needlefishes, and silversides were seldom collected.

Numerically, fishes representing seven families dominated the monthly collections. The most abundant fish families were anchovies (Engraulidae), herrings (Clupeidae), needlefishes (Belonidae), mojarras (Gerridae), porgies (Sparidae), drums (Sciaenidae), and mullets (Mugilidae). Excluding the anchovies, these families contributed from 48 to 97 percent of the standard monthly catch during 1972 (Table XV-11).

Table XV-10. Most abundant species of fishes as percent of the monthly catch from regular stations in the Ten Thousand Islands, 1972, excluding *Anchoa* spp.

Species	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Opisthonema oglinum	0.3				0.3	0.4	22.9	1.5	9.7	7.2	0.1	0.3
Brevoortia smithi	1.7	93.3	94.6	87.0	91.1	1.4	5.0	38.2	0.4	<0.1	0.5	15.1
Harengula pensacolae		<0.1			<0.1	0.8	3.6	1.2	50.2	22.2	28.1	12.7
Eucinostomus gula	20.8	0.4	0.3	0.1	0.2	1.9	2.3	2.6	3.8	7.6	10.8	10.3
Lagodon rhomboides	0.2	0.6	0.2	1.2	2.3	37.8	5.0	1.0	0.8	4.9	0.7	4.6
Bairdiella chrysura	0.1	0.7	<0.1	0.2	0.6	12.6	9.6	3.3	3.4	23.0	1.7	1.5
Total	23.1	95.1	95.2	88.5	94.6	54.9	48.4	47.8	68.3	65.0	41.9	44.5

Table XV-11. Most abundant families of fishes by number as percent of monthly catch from the regular stations in Ten Thousand Islands, 1972, excluding Engraulidae.

Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Clupeidae	2.0	93.3	94.6	87.0	91.4	2.6	31.5	40.9	60.3	29.5	28.7	28.1
Belonidae	4.2	0.3	0.3	0.4	0.2	0.4	2.5	2.1	1.4	3.4	3.2	12.5
Gerridae	40.2	2.7	1.4	3.4	2.2	10.7	20.9	12.8	16.5	24.0	34.3	23.2
Sparidae	0.5	0.6	0.2	1.3	2.3	38.2	5.2	1.1	0.8	5.1	0.9	0.6
Sciaenidae	0.3	0.9	<0.1	0.3	0.7	13.0	12.7	4.2	3.9	23.6	2.0	1.7
Mugilidae	0.3	0.1	0.2	0.6	0.3	1.2	1.8	5.8	2.6	0.3	7.9	13.4
Total	47.5	97.9	96.8	93.0	97.1	66.1	74.6	66.9	85.5	85.9	77.0	79.5

Fishing devices are notoriously selective by species and by size. Extrinsic factors (type of gear and sampling procedure) and intrinsic factors (behavior of the fishes, size, and diurnal sampling times) are responsible for variations in the catches (Pope, 1966). The surface trawling gear was extremely effective for smaller-sized pelagic fishes, such as clupeids, engraulids, strongylurids, and atherinids, while the otter trawl captured larger numbers of bottom dwelling fishes, such as sciaenids, gerreids, and sparids. Thus, both trawls complemented each other in the open bay areas. Seines were generally non-selective since they caught juvenile and adult fishes which inhabited the water column as well as the benthos.

The most abundant catches by gear and month were usually associated with the seasonal dominance of one or two species. The preponderance of juvenile yellowfin menhaden in March and of anchovies in June and October contributed to the peak surface trawl catches in those months (Figure XV-3). The largest mean catch with the otter trawl occurred in June and was due to an abrupt increase in the numbers of pinfish and pigfish in the collections. Peak catches at the seining stations were attributed to anchovies in January and to the scaled sardine at the beach stations in November (Figure XV-4).

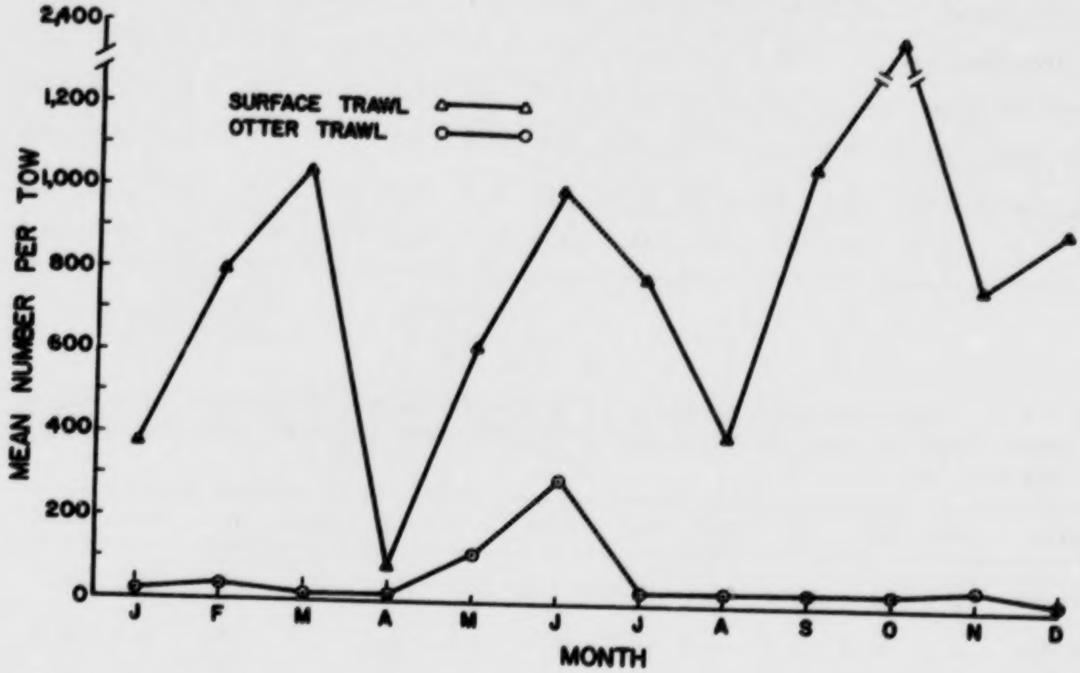

Figure XV-3. Distribution of the mean catches by number at the regular surface and otter trawling stations.

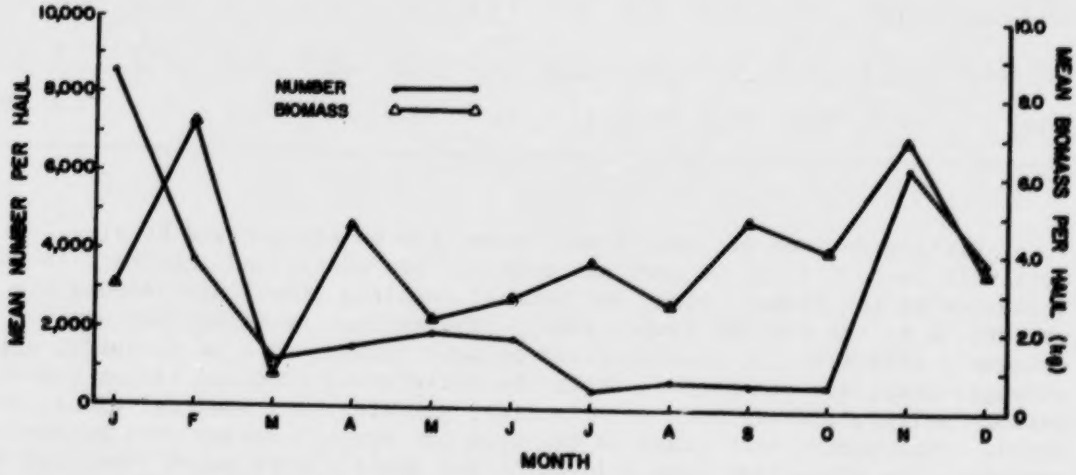

Figure XV-4. Distribution of the mean catches by number and by biomass at the regular seining stations.

By species, the largest total number in the standard monthly collections were recorded in June (61) and November (54) (Figure XV-5). Similar increases in the number of species occurred in the same two months with all three pieces of gear. The fewest species in the monthly catches occurred in March and April.

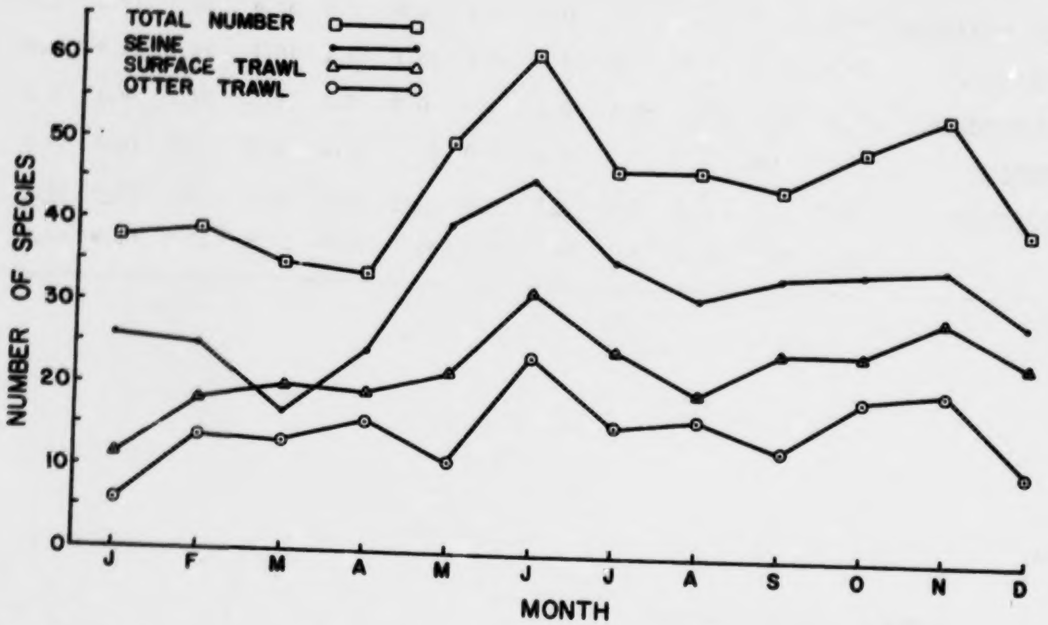

Figure XV-5. Number of fish species from the collections at the regular stations by type of gear and by total number per month.

Relative Abundance by Biomass

Biomass (wet weight) values are usually not determined in surveys of estuarine fishes (Tabb and Manning, 1961; Roessler, 1970; Gunter and Hall, 1965: Wang and Raney, 1972; and Springer and Woodburn, 1960), although McFarland (1963) maintained that the biomass of fishes yielded more ecological information than the numerical data. The current study represents the first time that measures of biomass were employed to assess the relative abundance of fishes in Southwestern Florida. The total biomass of fishes collected at the regular stations in the Ten Thousand Islands was 414.3 kg (Table XV-9).

By biomass, the most abundant fishes in our monthly collections, in decreasing order, were bay anchovy, southern stingray (Dasyatis americana), scaled sardine, fantail mullet (Mugil trichodon), striped mullet (M. cephalus), silver perch, and yellowfin menhaden. The monthly distribution of these dominant fishes in the regular catch, except for the southern stingray which only occurred sporadically, are presented in Table XV-12. These six species by biomass comprised 49.7 percent of the total catch. The distribution of the total mean monthly catches by biomass for the seine, surface trawl, and otter trawl are presented in Figures XV-4 and 6.

Table XV-12. Most abundant species of fishes by biomass as percent of the monthly catch from regular stations in the Ten Thousand Islands, 1972.

Species	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Brevoortia smithi	<0.1	7.4	20.7	2.2	15.2	0.1	0.6	20.7	0.2	<0.1	0.3	0.1
Harengula pensacolae	<0.1				<0.1	0.1	0.5	0.5	31.4	16.4	17.9	1.6
Anchoa mitchilli	58.6	28.2	19.4	3.0	7.8	10.2	16.1	8.1	16.7	19.7	15.8	22.9
Bairdiella chrysura	<0.1	0.2	<0.1	<0.1	0.3	7.4	0.8	0.6	2.3	24.9	0.5	0.5
Mugil cephalus		2.4			26.6	1.9	29.7	10.0	6.3	0.9	14.4	2.6
Mugil trichodon	0.2	0.1	3.2	3.5	0.5	1.0	1.6	14.7	14.0	0.8	17.0	37.0
Total	59.0	38.3	43.4	8.8	50.5	20.7	49.3	70.9	62.8	62.8	65.9	64.7

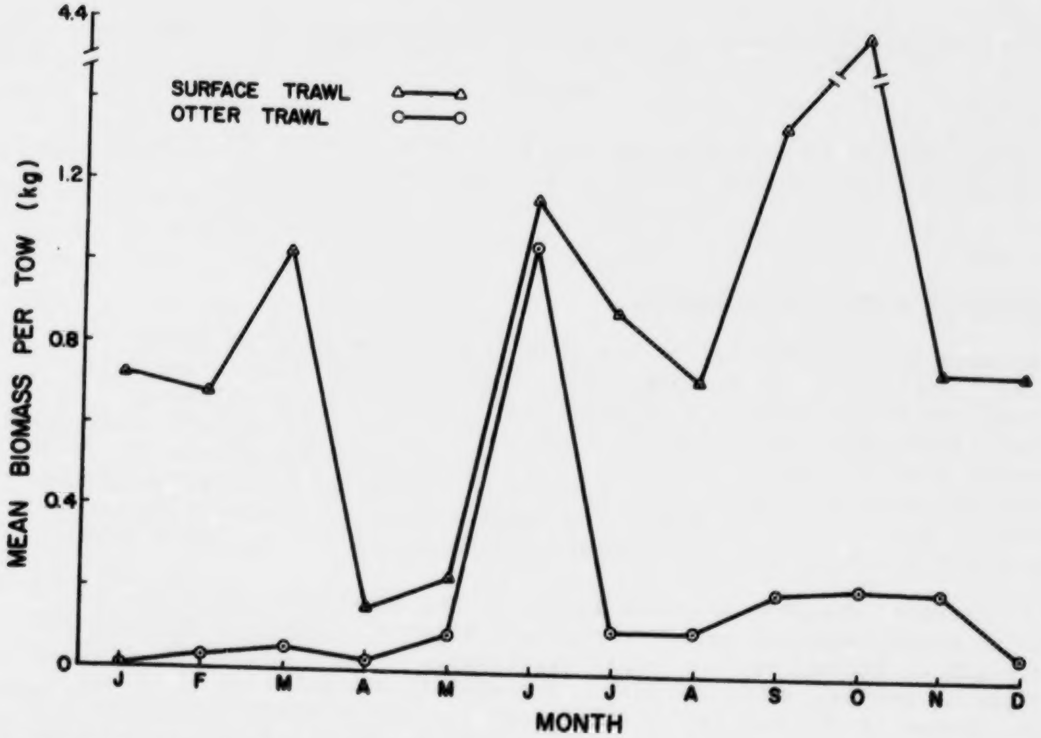

Figure XV-6. Distribution of the mean catches by biomass at the regular surface and otter trawling stations.

The monthly catch data at the regular stations indicate that the species of anchovies (Engraulidae) also dominated the fish biomass. In fact, the same seven families of fishes dominated the fish fauna of the estuaries as measured by biomass, as well as by numbers (Tables XV-13 and 11), respectively. On a biomass basis, these families comprised 23 to 96 percent of the monthly catch.

Table XV-13. Most abundant families of fishes by biomass as percent of monthly catch from regular stations in Ten Thousand Islands, 1972.

Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Clupeidae	0.1	7.4	20.7	2.2	15.3	0.2	1.9	21.4	36.1	19.9	18.2	1.8
Engraulidae	60.2	28.3	19.9	3.3	10.2	12.8	16.3	9.3	17.5	20.4	16.6	23.1
Belonidae	6.2	2.8	9.0	1.6	1.4	2.2	2.5	4.2	2.4	8.0	4.7	15.9
Gerridae	10.6	2.9	6.6	6.7	15.7	14.6	2.3	8.5	4.5	5.6	4.3	5.3
Sparidae	8.8	6.8	10.4	0.2	1.4	20.4	2.5	1.0	0.6	8.0	10.5	4.1
Sciaenidae	0.2	38.4	<0.1	5.5	0.8	8.1	1.1	0.8	2.5	25.1	0.5	5.8
Mugilidae	0.3	2.9	3.2	3.5	27.2	2.9	32.1	25.5	20.4	2.0	31.4	39.6
Total	86.4	89.5	69.9	23.0	72.0	61.2	58.7	70.7	84.0	89.0	86.2	95.6

In June, increases in the number of individuals, number of species, and biomass (Figures XV-3 through 6) were partially attributed to a reduction in the salinities of the estuarine waters. The highest salinity readings (39 ppt) were recorded at the regular stations in May; salinities had dropped 6 to 12 ppt at the time of the June sampling (Figure XV-7). June traditionally is the start of the rainy season in South Florida. In addition, shifts in the species composition such as 7- and 10-fold increases in the abundance of pigfish and pinfish along with a 100-fold decrease in the number of yellowfin menhaden, accompanied the seasonal decline in the June salinities (Table XV-10).

Distribution by Rank

The analyses of the percent composition by number and by biomass of the 40 most abundant fishes from the regular collections are presented in Table XV-14. The wide distribution and abundance of the bay anchovy was demonstrated by the dominance of this fish in both the numerical (75 percent) and the biomass compositions (18 percent).

Numerical and biomass abundance of many species showed a similar ranking. However, for the majority of species, their ranking by biomass and numerical composition as a percent of total catch was dissimilar. For example, the fantail and striped mullet ranked 3rd and 4th by biomass, but numerically, they ranked 10th and 25th, respectively. Snook, red drum, and gray (mangrove) snapper by weight ranked 14th, 18th and 30th; by number, none of these three

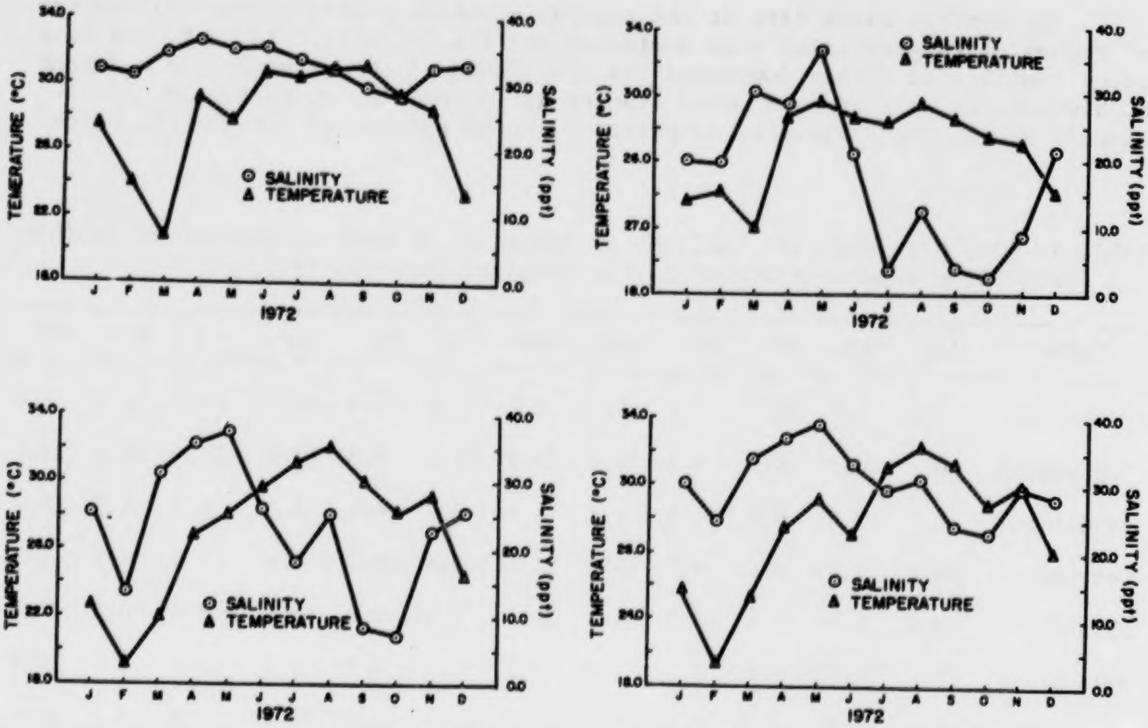

Figure XV-7. Water temperature and salinity readings for Round Key at seine Station 2 (upper left), for tidal stream off Fahka Union Canal at seine Station 5 (upper right), for Fahka Union Bay at surface trawl Station 7 (lower left), and for Fahkahatchee Bay at surface trawl Station 9)lower right).

popular sport fishes were among the 40 most numerous fishes in the regular collections (Table XV-14). In the present study, neither biomass nor numerical species compositions used alone were entirely adequate as a means of analyzing relative abundance. However, these data show the need to incorporate biomass values in future assessments of fish fauna.

Relative Abundance Between Bays

Relative abundance of fishes by species, number, and biomass with surface and otter trawling gear was compared between Fahka Union and Fahkahatchee Bays. Throughout the year, almost twice as many species of fishes were caught with surface and otter trawls in Fahkahatchee Bay than in Fahka Union Bay (Table XV-15). Numerically, surface trawl catches were slightly greater in Fahka Union Bay which was attributed to abundant catches of yellowfin menhaden in March and April, but the mean otter trawl catch in Fahkahatchee Bay was 58 percent greater than the returns from the other bay. The mean biomasses with the surface and otter trawls in Fahkahatchee Bay were substantially greater than in Fahka Union Bay.

Table XV-14. Percent species and biomass composition of the 40 most abundant fishes from the regular monthly stations in the Ten Thousand Islands, 1972.

Species	Composition by Number (%)	Rank	Species	Composition by Biomass (%)	Rank
Anchoa mitchilli	74.79	1	*Anchoa mitchilli*	18.40	1
Brevoortia smithi	15.09	2	*Dasyatis americana*	10.63	2
Harengula pensacolae	1.78	3	*Harengula pensacolae*	8.09	3
Anchoa hepsetus	1.59	4	*Mugil trichodon*	7.83	4
Lagodon rhomboides	1.13	5	*Mugil cephalus*	7.14	5
Bairdiella chrysura	0.97	6	*Bairdiella chrysura*	4.71	6
Eucinostomus gula	0.61	7	*Brevoortia smithi*	4.03	7
Opisthonema oglinum	0.54	8	*Pogonius cromis*	3.72	8
Menidia beryllina	0.41	9	*Archosargus probatocephalus*	3.56	9
Mugil trichodon	0.32	10	*Strongylura notata*	3.30	10
Hyporhamphus unifasciatus	0.31	11	*Lagodon rhomboides*	2.95	11
Strongylura notata	0.27	12	*Eucinostomus argenteus*	2.66	12
Membras martinica	0.23	13	*Diapterus plumieri*	2.32	13
Eucinostomus argenteus	0.19	14	*Centropomus undecimalis*	2.24	14
Orthopristus chrysoptera	0.18	15	*Dasyatis sabina*	2.00	15
Syngnathus scovelli	0.17	16	*Trachinotus falcatus*	1.90	16
Lucania parva	0.16	17	*Eucinostomus gula*	1.59	17
Floridichthys carpio	0.14	18	*Sciaenops ocellata*	1.37	18
Trachinotus falcatus	0.12	19	*Hyporhamphus unifasciatus*	1.18	19
Oligoplites saurus	0.12	20	*Opisthonema oglinum*	1.10	20
Jordanella floridae	0.11	21	*Chaetodipterus faber*	1.05	21
Poecilia latipinna	0.09	22	*Arius felis*	1.02	22
Cyprinodon variegatus	0.08	23	*Anchoa hepsetus*	0.86	23
Strongylura timucu	0.05	24	*Negaprion brevirostris*	0.81	24
Mugil cephalus	0.04	25	*Strongylura timucu*	0.68	25
Gobiosoma robustum	0.04	26	*Strongylura marina*	0.64	26
Hippocampus zosterae	0.04	27	*Orthopristis chrysoptera*	0.53	27
Diapterus plumieri	0.04	28	*Lepisosteus platyrhincus*	0.46	28
Cynoscion arenarius	0.03	29	*Sphoeroides nephalus*	0.44	29
Arius felis	0.03	30	*Lutjanus griseus*	0.35	30
Sphoeroides nephalus	0.03	31	*Sphyrna tiburo*	0.33	31
Cynoscion nebulosus	0.02	32	*Tylosurus crocodilus*	0.32	32
Strongylura marina	0.02	33	*Membras martinica*	0.31	33
Synodus foetans	0.02	34	*Bagre marinus*	0.29	34
Archosargus probatocephalus	0.02	35	*Floridichthys carpio*	0.21	35
Heterandria formosa	0.02	36	*Oligoplites saurus*	0.20	36
Lutjanus synagris	0.01	37	*Mugil curema*	0.20	37
Microgobius gulosus	0.01	38	*Caranx hippos*	0.12	38
Fundulus similis	0.01	39	*Elops saurus*	0.10	39
Chloroscombrus chrysurus	<0.01	40	*Paralichthys lethostigma*	0.09	40

Dissimilarities between these two bays existed in the composition of the bottom fishes and plants. In Fahkahatchee Bay, the presence of abundant grass beds (*Thalassia* - *Diplanthera*) provided an important habitat for numerous fishes, particularly pinfish and silverperch. These two fishes often dominated the otter trawl collections in this bay. Grassy areas are apparently a preferred habitat for pinfish as Hoese and Jones (1963) stated that the pinfish was the major fish species with the greatest biomass in the grass communities of Texas. In the present study, the sparse occurrence of these grasses and their associated fish fauna was judged to be responsible for the decreased catches in Fahka Union Bay. In summary on the basis of the catch data, we concluded that more favorable ecological conditions, particularly in reference to the structure of the bottom fish and plant communities, existed in Fahkahatchee Bay (essentially

Table XV-15. Comparison of yearly catches of fishes taken by surface and otter trawls between Fahka Union and Fahkahatchee Bays, Florida, 1972.

Gear	Number of Species	Number of Tows	Mean Number of Individuals	Mean Biomass (gm)
		Fahka Union Bay		
Surface trawl[a]	30	23	968.8	710.4
Otter trawl[b]	22	24	25.6	55.3
		Fahkahatchee Bay		
Surface trawl[c]	51	69	831.9	1,193.0
Otter trawl[d]	42	67	60.9	235.4

[a] = Station 7
[b] = Station 11
[c] = Stations 8, 9, and 10
[d] = Stations 12, 13, and 14

an undisturbed environment) than in Fahka Union Bay (a disturbed or stressed environment).

Distribution by Habitats

The distribution of fishes was related to environmental differences among the various estuarine and freshwater habitats. The total number of fish species collected with all types of gear from six aquatic habitats are summarized in Table XV-16. The occurrence of individual species by habitat are tabulated in Appendix MM. Fishes taken in the scheduled monthly collections (catch per unit effort) and in the monthly collections from the waterways in Fahkahatchee Strand are distinguished from those species collected at irregular intervals throughout the year during special studies, such as standing crop estimates, fish collections for pesticide analyses, and juvenile snook investigations. Also, the tabulation of fishes in Appendix MM serves as a checklist of fishes from the coastal waters of the Ten Thousand Islands and Fahkahatchee Strand.

Generally, sandy beach habitats in the chain of islands known as the Ten Thousand Islands are not extensive. In fact, many of the islands that boarder the open Gulf are devoid of sandy beaches, because of extensive stands of red mangrove trees lining the water edge. The surf zone in the Ten Thousand Islands is generally a low energy type; the occurrence of pounding surfs is usually restricted to storms or other hydrographic disturbances. The longest stretches of beach are found on Morgan Beach near Cape Romano, Kice Island, Marco Island, and Naples Beach, which are northwest of the main study area.

Shallow water reefs are characteristic of the Florida Keys, but they are absent from the area of the Ten Thousand Islands. Thus, members of the tropical

Table XV-16. A summary of the fish species from the coastal water habitats in the Ten Thousand Islands, 1972.

Habitat	Number of Species	Number of Families
1. Beach and adjacent waters	68	34
2. Middle reaches	89	42
3. Tidal streams in upper reaches	47	24
4. Tidal canals in upper reaches	59	25
5. Freshwater canals	24	10
6. Freshwater habitats in Fahkahatchee Strand	17	7

reef fauna, such as angelfishes (Chaetodontidae), grunts (Pomadasyidae), and wrasses (Labridae), were not represented in our faunal collections.

A total of 68 species were recorded from the beach habitat and adjacent waters. A number of clupeids, sciaenids, carangids, gerreids, strongylurids, and others accounted for 57 species collected in the surf zone during the regular monthly collections. Eleven additional species were taken in special collections along the beach or in nearshore waters.

Species unique to the catches from the beach habitat included lemon shark (Negaprion brevirostris), blacktip shark (Carcharhinus limbatus), permit (Trachinotus falcatus), smooth butterfly ray (Gymnura micura), northern kingfish (Menticirrus saxtilis), least puffer (Sphoeroides parvus), tarpon snook (Centropomus pectinatus), longsnout seahorse (Hippocampus reidi), and houndfish (Tylosurus crocodilus).

Two species, longsnout seahorse and least puffer, from the beach represented range extensions. The longsnout seahorse is common in the Carribean. Starck (1968) has the only previous record from the continental United States which was collected in the Florida Keys. Our single specimen was taken in a special tow off Round Key in April, 1972. Shipp and Yerger (1969) reported that the least puffer occurs in northern waters of the Gulf of Mexico and south to Apalachicola Bay. This species was also recorded from the Gulf of Campeche, Mexico. Our only specimen was collected at the beach seine station on Round Key in January, 1972. The identification of the least puffer was verified by Dr. Thomas McKinney, National Marine Fisheries Service, on the basis of taxonomic characteristics provided by Shipp and Yerger.

Of the six habitats (Table XV-16), the greatest number of species were recorded from the middle reaches of the estuary. This increase was attributed to greater sampling effort, as well as to environmental conditions in the bays, such as moderate salinities, a more abundant food supply, and a greater number of communities including *Diplanthera* - *Thalassia* beds, stands of red algae, oyster reefs, shallow mud flats, and tidal streams. Of the 89 fish species from this habitat, 16 species were taken in special studies not associated with the standard monthly unit-of-effort.

Other fishes that were only collected in the middle reaches of the estuary included the spotted eagle ray (*Aetobatus narinari*), jewfish (*Epinephelus itajara*), gag (*Mycteroperca microlepis*), highfin goby (*Blennius nicholsi*), Florida blenny (*Chasmodes saburrae*), Atlantic bumper (*Chloroscombrus chrysurus*), lookdown (*Selene vomer*), emerald parrotfish (*Nicholsina usta*), fringed flounder (*Etropus crossotus*), and great barracuda (*Sphyraena barracuda*). Other fishes inhabiting the middle reaches of the estuary, as well as the other specified habitats, were frillfin goby (*Bathygobius soporator*) from a high salinity tidal stream in north Fahkahatchee Bay and two species, naked goby (*Gobiosoma bosci*) and skilletfish (*Gobiesox strumosus*), which were retrieved from sedimentation traps in the bays. The skilletfish, a member of the clingfish family, is rarely captured with trawling gear or seines because of their secretive habits and preference for oyster communities or the underside of submerged wooden structures.

A few of the more abundant fishes in the middle reaches of the estuary were yellowfin menhaden, thread herring, scaled sardine, halfbeak (*Hyporhamphus unifasciatus*), bay anchovy, leatherjack, mojarras (four species), pinfish, silver perch, needlefishes (three species), pigfish, code goby, dwarf seahorse, fantail mullet (*Mugil trichodon*), Gulf pipefish (*Syngnathus scovelli*), gold-spotted killifish, and rough silverside (*Membras martinica*).

In past studies, many investigators, such as Phillips and Springer (1960), Tabb and Manning (1960), Gunter and Hall (1965), Roessler (1970), and others, encountered difficulties in differentiating between some of the above closely related species or their various ontogenetic stages. The major difficulty was the lack of adequate keys or taxonomic descriptions. Recent papers on juvenile and larval clupeids (Dahlberg, 1970; and Houde and Fore, 1973), needlefishes (Collette, 1968), and mullets (Futch, 1966) were invaluable in distinguishing these species. Meristic variations in specimens of halfbeak in our collections demonstrated that the genus *Hyporhamphus* (Miller, 1945) represented a species complex, that is, *unifasciatus* probably included at least two sympatric species in the Ten Thousand Islands. Following the present procedure, all members of this genus in Southwest Florida were designated as *unifasciatus* (Springer and Woodburn, 1960; and Bohlke and Chaplin, 1968).

Two distinct brackish water habitats were present in the upper reaches. Generally the tidal streams were natural waterways characterized by shallow depths (<1.0m) , strong currents, and narrow widths, while the tidal canals were dredged (man-made) channels possessing moderate depths (1.0 to 2.0 m), sluggish to moderate currents, and wider widths. The upper ends of many of these streams and canals were confluent with freshwater marshes and thus, represented the headwaters of the estuary (Carriker, 1967). Salinity patterns in these upper reaches continually shifted during the wet and dry seasons, as well as during the semi-diurnal tidal phases. Many freshwater and marine fishes moved up and down these headwater regions in response to the seasonal and daily changes in the salinity concentrations.

During the year, a greater number of species (59) were collected in the tidal canals than in the tidal streams (47). Most fishes in the upper reaches were either oligohaline or euryhaline species and thus, they exhibited a widespread distribution among the different aquatic habitats (Appendix MM). Florida gar, yellowfin menhaden, bay anchovy, tidewater silverside, mosquitofish, sailfin molly, spotfin mojarra, and rainwater killifish were the dominant fishes in these brackish waters. Favorable conditions of the habitat, such as an abundant food supply and few piscivorous predators, enhanced the well-being of young snook, redfish, and ladyfish, three popular sport fishes, that utilized these habitats as nursery grounds. In the snook investigation, all but 6 of 193 juveniles were captured in the upper reaches (mainly, tidal streams).

Dissimilarities between the freshwater habitats (man-made or dredged canals, such as GAC, Alligator Alley, and Tamiami Canals, and the various aquatic habitats in Fahkahatchee Strand) were discussed earlier in this chapter. More species of fishes were collected in the canals than in Fahkahatchee Strand (Table XV-16 and Appendix MM), possibly because the canals are inundated throughout the year, while many areas of the Strand dry-out during the dry season. Fishes unique to the canal habitats included the seminole killifish and the bluespotted sunfish from the eastern GAC Canal and the brook silverside from the Alligator Alley Canal, while the brown bullhead was only taken in a Strand lake (Ballard's). More extensive sampling in these areas undoubtedly would have increased the list of fishes from these habitats.

Distribution in Time

The monthly distribution of 134 species of fishes, largely collected during the 1972 biological year, are indicated in Appendix NN. Fishes identified from the regular estuarine and freshwater stations (Stations A_1 and A_2) were distinguished from those taken in other special collections. Because of the number of fishery studies in diverse habitats and the deployment of several types of sampling gear, no attempt was made to affix numbers to individual species, since comparisons of these data would be meaningless because of inherent gear selectivity. The addition of biomass values would have compounded this problem. However, seasonal patterns of distribution of the most abundant species and families by number and by biomass were satisfied to a certain extent in the prior tables and figures in the results.

Although subjective, a comparison of the estuarine species listed by habitat (Appendix MM) and by time of collection (Appendix NN) will furnish some general information on seasonality and relative abundance of the less numerous species. For instance, uncommon species, such as the bull shark (Carcharinus leucas), tarpon snook (Centropomus pectinatus) and highfin blenny (Blennius nicholsi) were recorded from a single habitat in a given month, whereas common species usually were observed in several habitats during a number of months. All of the freshwater fishes were permanent residents and probably would have been recorded in every month of the year (Appendix NN), had these areas been sampled more frequently.

Discussion

The present investigation represents the only extensive survey of the fish fauna of the Ten Thousand Islands and adjacent freshwater areas. Of the 134 species in our checklist (Appendix KK), subsequent collections will undoubtedly increase the number of fishes from these waters.

Along the southwestern coast of Florida, similar species of fishes dominate the fish fauna. In the Ten Thousand Islands, the most abundant fishes are anchovies, yellowfin menhaden, scaled sardine, pinfish, silver perch, and silver jenny. By far, the pelagic bay anchovy is the dominant species occurring in all zones of the estuary throughout the year. In a 3-year study of the fishes in Whitewater and Florida Bays, Tabb and Manning (1961) observed that the most abundant fishes were anchovies, mojarras, silver perch, pinfish, and code goby. Studies in other adjacent areas, such as Charlotte Harbor (Wang and Raney, 1971), the Caloosahatchee River and nearby estuaries (Gunter and Hall, 1965), and the Buttonwood Canal (Roessler, 1967), recorded a similar assemblage of dominant fishes.

Fish production in the mangrove-lined estuaries of the Ten Thousand Islands was illustrated by the occurrence of numerous juvenile sport, commercial, and forage fishes and shellfishes in the collections. Many of these species are estuarine-dependent, that is, either a portion of or in a few instances their entire life cycles, are spent in the estuaries.

Young of popular sport fishes in southwest Florida that utilize these waters as nursery grounds include the red drum, snook, ladyfish, gray (mangrove) snapper, lane snapper, sheepshead, tarpon, and spotted seatrout. Most of these species were spawned in the offshore waters of the Gulf and first entered the estuaries as post-larval or juvenile stages. In this group, only the spotted seatrout spawns in the bays, while the snook (Marshall, 1958) and the red drum (Yokel, 1966) reportedly spawn in the deep outer passes leading to the Gulf of Mexico. The early juvenile stages of gray snapper, spotted seatrout, red drum, sheepshead, and lane snapper initially are found in the grass (Diplanthera - Thalassia) beds in Fahkahatchee Bay and later move to other estuarine habitats. Post-larval and juvenile ladyfish, snook, and tarpon (Wade, 1969) inhabit the brackish water areas of the mangrove estuaries, such as tidal streams, ditches, canals, and marshes, which provide favorable environmental conditions for their growth and survival. As these young increase in size, they move to the higher salinity regions of the estuary. A description of tidal streams as a major nursery habitat for juvenile snook is presented in the following chapter.

Estuarine finfishes and shellfishes dominate the commercial fishery landings in the Gulf of Mexico. Twenty-three major commercial species were found to inhabit the estuary of Tampa Bay as immatures (Sykes and Finucane, 1964). All of these species were taken in various inshore habitats in our study area, except the red grouper, Epinephelus morio. Although not listed by Sykes and Finucane (op. cit.), juvenile jewfish, also a member of the grouper family, were fairly common in the bays of the Ten Thousand Islands during the summer and fall.

Pink shrimp, Penaeus duorarum, blue crab, Callinectes sapidus, and eastern oyster, Crassostrea virginica, are all dependent on the estuarine habitat for survival. Although oysters were not sampled with the trawling gear, oyster bars were present along the shorelines of the bays, in the channels, and at the mouths of rivers and creeks. Pink shrimp and blue crabs were taken at all trawling stations in the bays. Fahkahatchee Bay supports a large population of immature pink shrimp which were particularly abundant in the seagrass beds. Juvenile shrimp from the estuaries in this area are harvested as adults on the Tortugas and Sanibel fishing grounds (Costello and Allen, 1966). Shrimp are the most valuable fisheries resource in south Florida.

The different regions in the estuary varied in importance as nursery grounds (Appendix MM). Based on the distribution and abundance of juvenile fishes, these areas are listed in the decreasing order of importance as follows: bays in the middle reaches of the estuary; brackish water areas, such as tidal streams, canals, and marshes, in the upper reaches; and the open beaches in the lower reaches. Of the two bays that were intensely studied, Fahkahatchee Bay was a more productive nursery than was Fahka Union Bay. Fahkahatchee Bay featured a greater abundance of benthic vegetation and invertebrate fauna as compared to the stressed environment of Fahka Union Bay. Although not as many juvenile species inhabit the low salinity zone in the upper reaches, these areas provide a vital habitat for many fishes, such as snook, ladyfish, sheepshead minnow, tidewater silverside, and rainwater killifish. The sandy outer beaches served as a nursery ground for the least number of species, partially due to a less abundant supply of food and shelter. However, some species favored this region at certain times in their early life history. For example, juvenile permit were only collected at the beach stations in our area. Young scaled sardine and threadherring inhabited the bays during the summer; during the fall months, they were concentrated in the surf zone of the outer beaches.

To date, a serious threat to the well-being of the estuarine ecosystem in the study area concerns the presence of an extensive system of drainage and borrow canals, such as GAC and Tamiami Canals. These canals disrupt the seasonal water patterns and reduce the overland flow of fresh water to the estuaries. At the height of the winter drought in May, 1972, the lack of freshwater runoff created hypersaline conditions in Fahkahatchee Bay with salinities approaching 39.0 ppt. Even higher levels have been reported in previous years. The onset of the summer rains lowered the salinity levels in June. Hypersaline conditions upset the salinity transport mechanism by which larval and juvenile fishes and shrimp find their way into the estuary and remove the low salinity barrior which allows marine predators to enter the nursery grounds. Thus, the protective nature of the estuary is lost. Odum (1970) stated that the maintenance of a salinity gradient is essential for the survival and protection of estuarine-dependent species, particularly those that are spawned outside the estuary.

On the basis of our evaluation of the data collected during the present study, it is concluded that the estuary in the Ten Thousand Islands provides favorable habitats which supply food and shelter for numerous fishes and macroinvertebrates. Part of the catch taken by the sport and commercial fisheries is directly related to the production and growth of young individuals in the Ten Thousand Islands.

XVI - BIOLOGY OF JUVENILE AND ADULT SNOOK, CENTROPOMUS UNDECIMALIS, IN THE TEN THOUSAND ISLANDS

INTRODUCTION

The snook, Centropomus undecimalis, is an extremely popular sport and food fish from the mangrove-lined estuaries of southwest Florida. The fighting qualities of this species make it a worthy adversary for both novice and seasoned fisherman, and its fillets are a gourmet's delight. This species is prevalent in the tropical and subtropical waters of south Florida along both the east and west coasts. The most abundant concentrations are found in the Ten Thousand Islands. This area also supports the main spawning grounds which reportedly occur near the outer passes leading to the Gulf of Mexico (Marshall, 1958). A thorough understanding of the biology and ecology of the snook is a necessary prerequisite for the proper management of the species.

Most of the prior investigations on the snook dealt primarily with the adults. Information on migration, age, and growth (Volpe 1959); general biology and historical data on the commercial fishery (outlawed in 1957) (Marshall, 1958); osteology (Fraser, 1958); and taxonomy (Rivas, 1962) were among the more comprehensive works. The few references on the biology of the juveniles included those on the food habits from a marsh habitat (Harrington and Harrington, 1961); on range extension (Lunz, 1953, and Martin and Shipp, 1971); and on general ecology (Springer and Woodburn, 1960, and Linton and Rickards, 1965).

Many aspects of the biology of the snook are still unknown. This paper presents the results of a study on tidal-stream habitats, length-weight relationships, food habits, and seasonal occurrences of juveniles and food and feeding habits of the adults from the Ten Thousand Islands, Florida.

MATERIALS AND METHODS

The study commenced in November 1971 and continued through December 1972. Juvenile snook were collected from tidal streams and canals in the upper reaches of the estuary. The selection of sampling sites was based on accessibility and the frequent presence of juveniles.

All juveniles were captured with a 15.2 m by 1.2 m nylon (Delta style) bag seine. The wings were constructed of 0.64-cm bar mesh and the bag of 0.3-cm bar mesh. Young snook were immediately preserved in a 5-percent solution of formalin in saline water. Biological data on standard, fork, and total lengths; wet weights; and stomach contents were recorded in the laboratory.

Specimens of adult snook were obtained at marinas on the Isle of Capri, Marco Island, and the GAC Remuda Ranch; from seine collections; and by hook-and-line during the summer. Data on lengths, sex, stages of gonadal development, and stomach contents were usually taken in the field; whereas, food items were analyzed in the laboratory.

A total of 454 snook were examined during an intensive study of the food relationships of this species. The 183 juveniles (142 stomachs with food) ranged in length from 14 to 196 mm, and the 271 adults (127 stomachs with food) varied from 224 to 1,020 mm in length. The adults were collected during the summer, and the juveniles were taken during the summer and fall.

All length measurements of fishes in this paper were of fork length (anterior extremity of closed jaws to the tip of the rays in the center of the caudal fin) to the nearest 1.0 mm, unless stated otherwise. Wet weights were taken with a dial-type balance (1,600-gm capacity) to the nearest 0.1 gm.

The analysis of the physical and chemical characteristics of estuarine waters followed the procedures outlined in the manual by the Environmental Protection Agency (1971), except for salinity and water temperatures which were taken with a salinometer.

HABITATS OF JUVENILES

Numerous aquatic zones (outer beaches, open bays, and freshwater canals) were searched before the nursery grounds of juvenile snook were located in the Ten Thousand Islands. Marshall (1958) was unsuccessful in his attempts to capture juveniles from this area. In our collections, young snook were only taken in the brackish waters of tidal streams and in dredged canals. Other features of these habitats included shallow depths, currents, shifting salinities, warm water temperatures, soft mud bottoms with little vegetation, often shoreline stands or clumps of red (*Rhizophora mangle*) or white (*Laguncalaria racemosa*) mangroves, an abundance of small food organisms, and few aquatic predators. Some stream habitats were contiguous with adjacent marshy areas during the rainy season. The sampling stations are described in Table XVI-1. The waters of all stations drained into the lower bays of the estuary and eventually into the Gulf of Mexico.

Table XVI-1. Descriptions of habitats where juvenile snook, *Centropomus undecimalis*, were collected in Ten Thousand Islands, Florida, 1971-1972.

Station Number	Location	Description	Mean Water Depth (m)	Bottom Type	Shoreline Vegetation	Tidal Current
1	Tamiami Trail, 1.6 km east of Collier-Seminole State Park	Tidal canal at upper reaches of Blackwater River	1.0	Soft mud and filamentous algae	Roadside weeds with scattered red mangrove and marshes	Moderate
2	East Naples, Barefoot Williams Road	Tidal canal confluent with Henderson Creek	1.0	Soft mud and sand	Grasses	Sluggish
3	East Naples, Barefoot Williams Road	Tidal ditch empties into upper end of Station 2	0.3	Firm mud and sand	Roadside weeds with scattered palms and buttonwood	Sluggish to moderate
4	East Naples, access road to KOA Campgrounds, west of Hwy. 951	Tidal stream branching off Henderson Creek	0.6	Soft mud	Stands of white mangrove	Moderate
5	North Fahkahatchee Bay, 120 m east of mouth of East River	Tidal stream	1.2	Firm mud and sand	Stands of red mangrove	Rapid

Juveniles were reported from similar stream habitats by other investigations. On Sapelo Island, Georgia, Linton and Rickards (1965) collected specimens from the headwaters of tidal creeks; but none were taken at the creek mouths, in the sounds, or on the outer beaches. In Tampa Bay, Springer and Woodburn (1960) seined 35 specimens, 26.6 to 191.0 mm SL, from a man-made bayou canal. They stated that "the preferred habitats of the young are protected bodies of water usually of small surface area and shallow depths." Based on juvenile specimens stored in various museums, Marshall (1958) concluded that young snook in Florida inhabited the marginal areas of the estuary, such as drainage streams, creeks, shorelines, small ditches, and man-made tributaries.

Marshlands also serve as major nursery areas for juvenile snook. This type of habitat was described by Harrington and Harrington (1961). They found juveniles in a seasonally inundated salt marsh that was adjacent to the brackish waters of the Indian River, Florida. Drought conditions existed in the marsh until flooding occurred in September due to a combination of heavy rainfall and high tides. Invading fishes included juvenile snook, as well as young tarpon (*Megalops atlantica*), ladyfish (*Elops saurus*), and several other species. Major characteristics of the marsh habitats were salinities ranging from 20.0 ppt to hypersaline conditions, high water temperatures, sand and peat substrate, plentiful supply of forage organisms, and rooted vegetation consisting of thick beds of saltwort (*Batis maritima*) and pneumatophores of the mangroves.

HYDROGRAPHIC DATA ON JUVENILES

Juveniles were taken at five stations during numerous stages of the tidal cycle (Table XVI-2). The salinity ranged from lows of 0.3 ppt to a high of 29.7 ppt. A statistical relationship was not demonstrated between the positive seine hauls (46) and the salinity of the water ($r = 0.23$, 44 d.f.). It was thought that juveniles of a given size (length) might be taken more frequently at a preferred salinity. But again, no correlation was shown between salinity and individual sizes ($r = 0.21$, 191 d.f.). However, it was evident from the collections that juvenile *C. undecimalis* are usually found in brackish waters in the Ten Thousand Islands.

The warmest water temperatures were recorded during the summer months; temperatures gradually declined to a low of 18.7°C in the late fall (Table XVI-2). Colder water temperatures occurred at night, but all sampling took place during daylight hours. A statistical correlation could not be established between the positive collections and the water temperature. Also, no correlation existed between the size of the juveniles and the temperature. Marshall (1958) remarked that snook could not tolerate water temperatures less than 15.5°C (about 60°F). Mortality of snook following sudden cold spells near Sanibel Island, Florida, were discussed by Storey and Gudger (1936) and Storey (1937).

Measurements of selected chemical parameters were made monthly from three tidal stream habitats from June through December 1972 (Table XVI-3). No comparative chemical parameters for juvenile snook habitats were found in the literature.

PESTICIDES

Three snook were analyzed for the presence of 23 pesticides distributed among a class of compounds known as chlorinated hydrocarbons, organophosphates, and organic carbamates. Concentrations of four chlorinated hydrocarbons (DDE,

Table XVI-2. Temporal, spatial, and hydrological data on all collections of juvenile snook, Centropomus undecimalis, from the Ten Thousand Islands, Florida, 1971-72.

Date	Station	Salinity (ppt)	Temperature (C)	Tidal Stage	Juvenile Fish	
					Number	Size Range (mm)
1971						
17 Nov.	1, 2	1.5-19.7	22.7-25.4	Ebb, Flood	5	123-178
24 Nov.	2	15.9	27.4	Flood	1	104
13 Dec.	1, 2, 3	18.9-20.7	27.5-27.9	Ebb	4	89-184
1972						
22 June	3	0.5	32.6	Ebb	2	24-25
23 June	3	0.5	32.9	Ebb	1	22
6 July	2	5.3	35.4	Ebb	3	14-35
20 July	1, 3	0.6-3.0	27.1-27.3	Flood, Ebb	4	27-37
1 Aug.	4	1.2	30.3	Ebb	2	14-57
11 Aug.	4	7.4	31.8	Flood	3	35-91
15 Aug.	2, 4	0.5-4.9	29.9-32.5	Ebb	3	30-62
22 Aug.	2, 4	8.5-9.3	27.2-27.8	Flood	5	40-104
24 Aug.	4	3.4	30.4	Flood	5	38-92
25 Aug.	4	2.4	28.2	Flood	2	22-99
28 Aug.	4	2.2	31.1	Flood	3	29-98
31 Aug.	3, 4	0.4-0.5	26.8-26.9	Ebb	12	31-101
14 Sept.	4	0.4	30.7	Ebb	2	67-94
15 Sept.	3, 4	0.4-0.5	28.8-29.3	Ebb	11	35-107
22 Sept.	3	8.7	28.7	Flood	2	116-121
28 Sept.	4	0.3	27.7	Ebb	6	60-95
29 Sept.	3, 4	0.3-0.5	28.5-28.6	Ebb	10	67-153
5 Oct.	3, 4	0.3-0.4	23.5-24.3	Ebb	7	22-110
12 Oct.	4	0.3	25.7	Ebb	19	55-161
17 Oct.	3, 4	1.6-7.0	29.2-29.9	Ebb	3	76-124
20 Oct.	3	2.0	25.0	Flood	3	92-148
27 Oct.	5	29.7	26.8	Ebb	6	58-121
8 Nov.	4	3.0	28.9	Ebb	26	70-196
13 Nov.	3, 4	6.9-13.0	28.6-29.6	Ebb	6	51-146
15 Nov.	3	10.3	27.[illegible]	Ebb	7	82-117
24 Nov.	4	1.6	19.4	Ebb	14	63-149
2 Dec.	4	1.5	18.7	Ebb	4	30-70
6 Dec.	4	2.4	24.2	Ebb	2	46-47
8 Dec.	4	12.9	28.0	Flood	1	41
12 Dec.	1	7.1	23.5	Ebb	6	26-49
29 Dec.	4	14.4	19.0	Ebb	3	48-64

DDD, DDT, and PCB's) were detected in two subadulults and one adult snook (Table XVI-4). No detectable concentrations were found for 19 other pesticides (aldrin, lindane, chlordane, chlorobenzilate, deldrin, endrin, heptachlor epoxide, heptachlor, methoxchlor, toxaphene, diazinon, guthion, methyl parathion, malathion, ethion, trithion, dimethoate, mirex and parathion).

Because of the small sample size and the lack of comparative data on snook from the literature, no firm conclusions on the persistence and effects of DDE, DDD, DDT, and PCB's on the well-being of snook can be made at this time. The carnivorous diet of the snook and low levels of similar pesticides

Table XVI-3. Physical and chemical characteristics of water collected monthly from three tidal streams inhabited by juvenile snook, June to December, 1972.

Parameter	Mean	Range
pH	7.5	7.1 to 7.6
Temperature (C)	28.8	23.5 to 33.7
Salinity (ppt)	5.4	0.2 to 21.0
Conductivity (millimhos/cm)	9.5	0.3 to 34.8
Chloride (mg/l)	2,115.8	38.4 to 9,322.0
Dissolved oxygen (mg/l)	5.9	3.1 to 9.3
Total hardness (mg/l as $CaCO_3$)	956.9	70.0 to 3,400.0
Total alkalinity (mg/l as $CaCO_3$)	206.8	52.9 to 309.0
Total phosphorus (mg/l)	0.10	0.04 to 0.17
Total soluble phosphorus (mg/l)	0.03	<0.02 to 0.05
Total Kjeldahl nitrogen (mg/l)	1.36	0.87 to 1.80
Total soluable Kjeldahl nitrogen (mg/l)	0.93	0.80 to 1.24

Table XVI-4. Analyses of pesticides in snook, *Centropomus undecimalis*, in Ten Thousand Islands, Florida, 1972.

			Chlorinated Hydrocarbons			
Date	Location	Length (mm)	DDE (μg/kg)	DDD (μg/kg)	DDT (μg/kg)	PCB's (μg/kg)
Jan. 26	Henderson Creek	140	40.0	56.0	12.0	120.0
Jan. 26	Henderson Creek	206	42.0	51.0	11.0	85.0
July 28	Fahkahatchee Bay	335	13.0	5.4	ND[a]	ND[a]

a = Not detectable

in forage fishes from nearby waterways (see Chapter XI on pesticides), lead to the conclusion that this predator acquired these pesticides through the food chain. These results also showed that some pesticides have become an integral component of the coastal marshes, streams, and bays in southwest Florida.

ASSOCIATED ORGANISMS

The occurrence of other fishes and macrocrustaceans taken in the same collection along with juvenile snook from four sites (Stations 1, 2, 3, and 4) are listed in Table XVI-5. These associated animals were sorted from 15 randomly selected collections or 33 percent of the total number of positive hauls. Only a few fishes, such as redfin needlefish (*Strongylura notata*), Florida gar (*Lepisosteus platyrhincus*), and perhaps other young-of-the-year snook, were of sufficient size to prey upon juvenile snook. The fact that these juveniles inhabit low salinities, largely free of piscivorous predators, may operate as a survival adaptation for the species. In turn, most of the smaller fishes were utilized as forage by the snook.

Table XVI-5. Associated macrocrustaceans and fishes collected with juvenile snook during 15 randomly selected seine hauls at four stations in Ten Thousand Islands, Florida, June through December, 1972.

Species	Number of Times Present	Percent of Total Number of Hauls	Total Number of Individuals
Macrocrustaceans			
Penaeus duorarum	2	13.3	2
Palaemonetes intermedius	2	13.3	38
Palaemonetes pugio	8	53.3	261
Callinectes sapidus	8	53.3	40
Fishes			
Lepisosteus platyrhincus	1	6.7	1
Elops saurus	1	6.7	2
Brevoortia smithi	2	13.3	366
Anchoa hepsetus	2	13.3	6
Anchoa mitchilli	4	26.7	404
Arius felis	1	6.7	2
Strongylura notata	1	6.7	2
Strongylura timucu	1	6.7	1
Adinia xenica	3	20.0	3
Cyprinodon variegatus	8	53.3	279
Floridichthys carpio	2	13.3	10
Fundulus confluentus	5	33.3	30
Fundulus grandis	2	13.3	6
Jordanella floridae	2	13.3	6
Lucania goodei	2	13.3	2
Lucania parva	12	80.0	448
Gambusia affinis	8	53.3	516
Heterandria formosa	1	6.7	2
Poecilia latipinna	12	80.0	773
Menidia beryllina	15	100.0	3,629
Lepomis gulosus	2	13.3	2
Lepomis macrochirus	1	6.7	1
Lepomis microlophus	2	13.3	24
Lepomis punctatus	1	6.7	2

Table XVI-5. Associated macrocrustaceans and fishes collected with juvenile snook during 15 randomly selected seine hauls at four stations in Ten Thousand Islands, Florida, June through December, 1972. Continued.

Species	Number of Times Present	Percent of Total Number of Hauls	Total Number of Individuals
Micropterus salmoides	1	6.7	2
Diapterus plumieri	6	40.0	72
Eucinostomus argenteus	14	93.3	256
Eucinostomus gula	1	6.7	8
Archosargus probatocephalus	1	6.7	3
Lagodon rhomboides	2	13.3	18
Cynoscion arenarius	1	6.7	3
Cynoscion nebulosus	1	6.7	1
Leiostomus xanthus	2	13.3	3
Pogonias cromis	1	6.7	5
Sciaenops ocellata	2	13.3	6
Mugil cephalus	4	26.7	77
Mugil curema	1	6.7	1
Mugil trichodon	2	13.3	2
Gobiosoma robustum	4	26.7	6
Lophogobius cyprinoides	8	53.3	148
Microgobius gulosus	2	13.3	11
Achirus lineatus	1	6.7	1
Trinectes maculatus	7	46.7	11

LENGTH CONVERSION FACTORS

To provide comparisons of length measurements with the published data of other investigations, conversion factors were calculated to convert one type of measurement to another. Empirical data on standard-, fork-, and total-length measurements were recorded from 175 juvenile snook within a size range of 14 to 196 mm FL. Linear regressions were determined by the method of least squares. Conversion factors and statistics describing the length relationships in mm were as follows:

$$SL = -0.369 + 0.870\ FL \qquad r = 0.999 \qquad p = 0.01$$
$$FL = -0.424 + 1.150\ SL$$

$$FL = -1.531 + 0.909\ TL \qquad r = 0.998 \qquad p = 0.01$$
$$TL = 1.684 + 1.100\ FL$$

$$SL = -0.577 + 0.789\ TL \qquad r = 0.999 \qquad p = 0.01$$
$$TL = 0.732 + 1.268\ SL.$$

Juvenile snook, less than 14 mm FL, may not conform exactly to the above conversion factors.

LENGTH-WEIGHT RELATIONSHIPS OF JUVENILES

The relationship of fork length to weight was derived from the following equations (Lagler, 1956):

$$\log a = \begin{array}{l} \Sigma\log W\cdot\Sigma(\log L)^2 \\ \\ -\Sigma\log L\cdot\Sigma(\log L\cdot\log W) \end{array}$$

$$n = \frac{\Sigma\log W-(N\cdot\log a)}{\Sigma\log L}$$

$$\log w = \log a + n\cdot\log L,$$

where a and n are constants, W is the wet weight in gm, and L is the fork length in mm. In the current study, the calculated length-weight formula was:

$$\log W = -4.7730 + 2.8758\cdot\log FL.$$

The correlation coefficient for this formula was 0.998.

The log-log graph of weight as a function of length for 193 juvenile snook is shown in Figure XVI-1. If either the weight or the length of the fish is unknown, the log-log graph can be used to estimate the other value. However, the logarithmic formula is more precise in determining an unknown weight or length measurement.

The coefficient of condition (K) is a numerical measure of the well-being or relative robustness of fish (Lagler, 1956). Coefficient values of juveniles were calculated from the following equation:

$$K_{FL} = \frac{W(10^5)}{L^3},$$

where W is the weight in gm, L is the fork length in mm, and the factor of 10^5 reduces the number of decimals in the K value. Condition values are useful in comparing the same fish from different areas to determine the suitability of habitats or environmental changes.

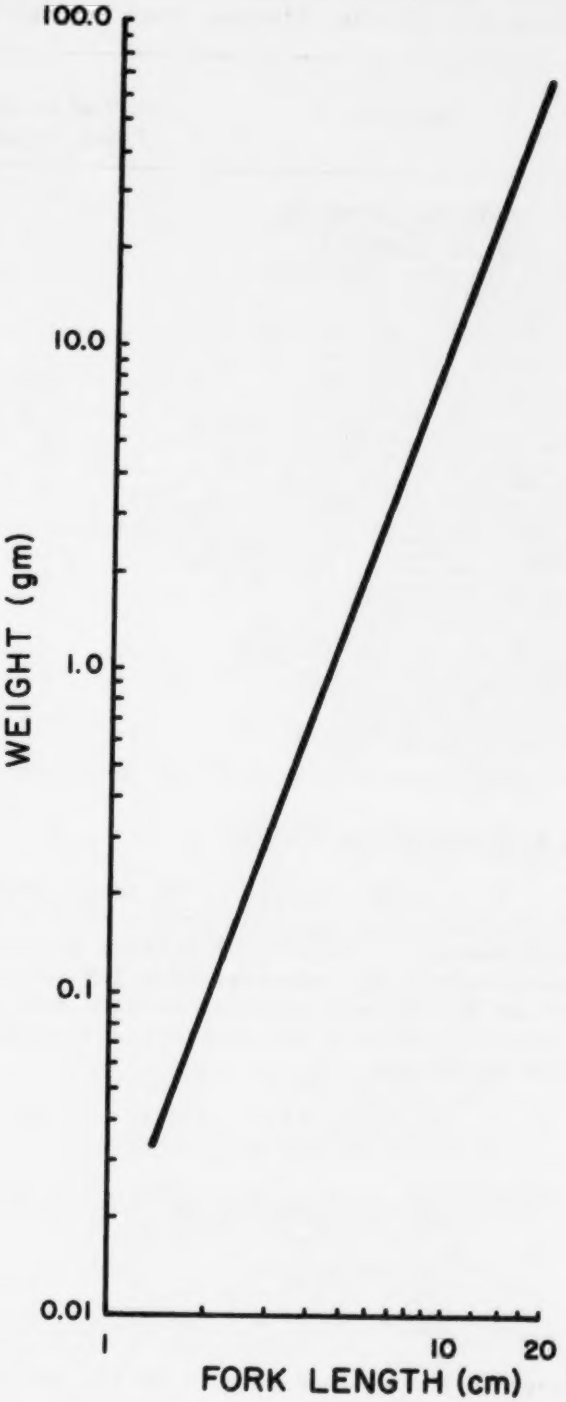

Figure XVI-1. The length-weight relationship (log W = -4.7730 + 2.8758·log FL) of juvenile snook in the Ten Thousand Islands, Florida.

The average condition value for juvenile snook from tidal stream habitats in the Ten Thousand Islands was 1.05. Condition factors ranged from a low of 0.77 to a high of 1.52. There was a slight, but non-significant, increase in condition values associated with an increase in length. Overall, the snook appeared to be in good condition. No comparative values on young snook from other regions were found in the litereature.

OCCURRENCE AND GROWTH

Study sites established in the fall of 1971 were sampled twice a month from January 1972 until the initial members of the 1972-year-class (two specimens 24.0 and 25.0 mm in length) were captured on June 22 (Table XVI-2). The sampling effort intensified after this date as time permitted, since a new year-class was entering the nursery grounds. A steady increase in the size of the juvenile population occurred during the remainder of the summer and into the fall, reaching peak abundance in November. The monthly mean number of juveniles per positive seine haul was as follows: June - 1.5; July - 2.3; August - 3.2; September - 4.4; October - 5.4; November - 10.6; and December - 3.2. No definitive records were kept on the negative hauls that occurred on several occasions. These studies clearly show that juveniles are found in the upper reaches of the estuary during the summer and fall months.

The monthly length-frequency distribution for 193 juvenile snook that were captured during the study are depicted in Figure XVI-2. Combined totals were presented for a couple of months because of the small sample size. Juveniles taken in November and December 1971 were considerably larger than those obtained in December 1972. The smaller-sized juveniles in the December collections in 1972 were attributed either to colder water temperatures which caused the larger juveniles to migrate to the bays, or to a late fall spawning period in 1972 compared to 1971 (Table XVI-2).

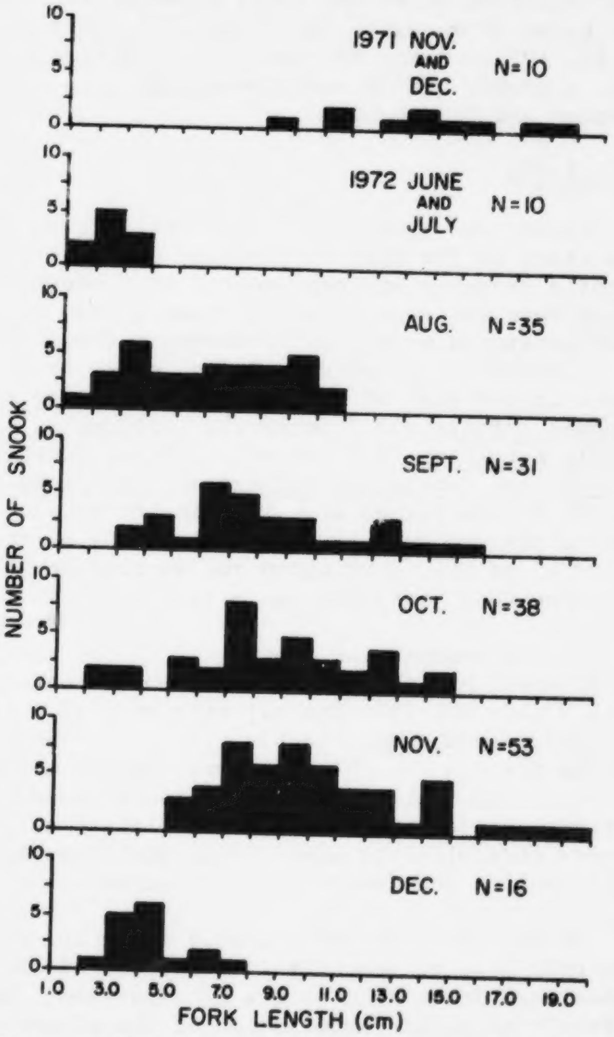

Figure XVI-2. Length-frequency distribution of 193 juvenile snook from the Ten Thousand Islands, Florida, 1971-72.

Juvenile snook grow at the rate of about 1.0 mm per day, at least during the warmer months. This estimate was derived from the following data: (1) the monthly length-frequency graph (Figure XVI-2), (2) the size of the juveniles at the time of collection (Table XVI-2), and (3) the commencement of the spawning season based on gonadal stages of development in the adults.

The spawning season of the snook in the Ten Thousand Islands occurs from the first of May to about the middle of November. In May, several adult males were sexually mature (running-ripe), while many females were in advanced stages of maturing. Marshall (1958) stated that spawning started in June, but he was unable to examine gonadal development during May.

The growth rate of 1.0 mm per day correlated with our estimate of the start of the spawning season. For example, the juvenile snook (102 mm TL) that was collected on August 11, 1972, and that grew at a daily rate of 1.0 mm, would back calculate to an estimated spawning date of about May 1. Also, a 204-mm TL fish taken on December 13, 1971, would give an estimated spawning time of about May 23, 1971. Since the metabolic requirements of fish are related to temperature, a slower growth rate presumably occurs during the colder periods in November and December.

FOOD HABITS

Fishes and crustaceans (shrimps, crabs, and zooplankton) comprised the main food items in the diet of juvenile snook. Fishes occurred in 77.5 percent of juvenile stomachs and represented 80.8 percent of the total food volume. Thus, fishes were the most important item in the diet. Piscivorous prey of the juveniles consisted mostly of livebearers (Poeciliidae), killifishes (Cyprinodontidae), and silversides (Atherinidae) (Table XVI-6). By total volume, the most abundant fishes in the diet of the juveniles were Poecilia latipinnia (34.9 percent), Gambusia affinis (12.7 percent), Lophogobius cyprinoides (7.7 percent), and Menidia beryllina (3.8 percent). Other identifiable fishes included Fundulus confluentus, Cyprinodon variegatus, Adenia xenica, and Scianops ocellata. Of the 138 forage fishes appearing in the stomach contents, 70.2 percent were identifiable to species. In their study of the food habits of juvenile snook (up to 45 mm SL), Harrington and Harrington (1961) failed to identify the species of fishes that juveniles had preyed upon.

Fishes represented about half of the total diet of the adults (by occurrence and volume), but fishes were less important as food in comparison to the juveniles (Table XVI-7). The majority of fishes identified in adult stomachs, such as Lagodon rhomboides, Anchoa mitchilli, Harengula pensacolae, Eucinostomus gula, Synodus foetens, and Floridicthys carpio, typically inhabit the higher salinity regions of the estuary. Forage fishes found in brackish and freshwater areas were also preyed upon. Snook are classed as a euryhaline species because they possess physiological adaptations enabling them to travel back and forth between highly saline and freshwater environments.

Of the 93 fishes distributed among 10 families in the adult stomachs, we were only able to identify 23.6 percent of these to species; the unidentifiable fishes were in various stages of digestion. Marshall (1958) encountered similar difficulties in his examination of the stomach contents of 128 adults (52.3 percent had empty stomachs), as he only identified seven species belonging to six families. Two of the fishes, Mugil cephalus and Orthopristis chrysoptera, were not noted in the current study.

Table XVI-6. Stomach contents of 183 juvenile snook, 142 of which contained food, from Ten Thousand Islands, Florida, June to December 1972.

Food Item	Numerical Total	Percent Frequency of Occurrence	Percent of Total Volume
Arthropoda			
Crustacea			
Cladocera	2	0.7	<0.1
Ostracoda	3	0.7	<0.1
Copepoda	38	6.3	<0.1
Amphipoda	13	0.7	<0.1
Decapoda			
Penaeidae			
Penaeus duorarum	6	4.2	3.8
Palaemonidae			
Palaemonetes pugio	9	5.6	3.6
P. vulgaris	1	0.7	0.2
P. spp.	28	18.3	7.9
Portunidae	5	2.8	1.8
Insecta			
Corixidae	5	2.8	0.5
Unidentifiable nymphs	3	2.1	0.9
Vertebrata			
Osteichthyes			
Cyprinodontidae			
Adenia xenica	1	0.7	0.7
Cyprinodon variegatus	2	1.4	1.2
Fundulus confluentus	3	2.1	1.4
Lucania parva	6	4.2	5.0
Poeciliidae			
Gambusia affinis	47	23.2	12.7
Poecilia latipinnia	25	16.2	34.9

Table XVI-6. Stomach contents of 183 juvenile snook, 142 of which contained food, from Ten Thousand Islands, Florida, June to December 1972. Continued.

Food Item	Numerical Total	Percent Frequency of Occurrence	Percent of Total Volume
Atherinidae			
Menidia beryllina	8	5.6	3.8
Sciaenidae			
Scianops ocellata	1	0.7	0.9
Gobiidae			
Lophogobius cyprinoides	4	2.8	7.7
Unidentifiable fishes	41	26.8	12.5
Planta			
Algae	2	0.7	<0.1
Vascular plants	6	2.1	0.4
SUMMARY			
Microcrustaceans	56	6.3	0.1
Shrimps	44	24.6	15.5
Crabs	5	2.8	1.8
Insects	8	4.2	1.4
Fishes	138	77.5	80.8
Plant material	8	2.8	0.4

Crustaceans were of secondary importance in the juvenile diet, since this group only represented approximately 20 percent of the food intake by percent occurrence and volume (Table XVI-6). Microcrustaceans (copepods, cladocerans, ostracods, and amphipods) were selected as food by the smaller juveniles. Of the shrimps, grass shrimps (*Palaemonetes pugio* and *P. vulgaris*) constituted a greater porportion of the diet than the pink shrimp (*Penaeus duorarum*). Volumetrically, palaemonid and panaeid shrimps comprised 11.7 percent and 3.8 percent of the total food intake, respectively. Crabs were of little importance in the diet of juveniles (1.8 percent by volume). Also, juveniles preyed upon aquatic insects (corixid nymphs and others) to a limited extent.

Overall, crustaceans, composed of crabs and shrimps, were of greater importance in the diet of adult snook than in juveniles. Crabs occurred in 48.0 percent of all adult stomachs and represented 32.3 percent of food volume, while various shrimps comprised 35.4 percent by occurrence and 9.6 percent by volume of the total diet. The importance of crabs as a food item was not in agreement with Marshall (1958), who reported that crabs only represented 4.4 percent by volume of the snooks' diet in the Ten Thousand Islands.

Table XVI-7. Stomach contents of 271 adult snook, 127 of which contained food, from Ten Thousand Islands, Florida, May to August 1972.

Food Item	Numerical Total	Percent Frequency of Occurrence	Percent of Total Volume
Crustacea			
Isopoda	1	0.8	0.1
Decapoda			
Astacidae			
Procambarus alleni	1	0.8	1.0
Penaeidae			
Penaeus duorarum	85	29.1	9.1
Palaemonidae			
Palaemonetes intermedius	3	1.6	0.1
P. spp.	6	2.3	0.1
Alpheidae			
Alpheus heterochaelis	2	1.6	0.3
A. spp.	1	0.8	<0.1
Hippolytidae			
Hippolyte pleuracantha	1	0.8	<0.1
Paguridae			
Paguristes spp.	1	0.8	<0.1
Pagurus spp.	1	0.8	<0.1
Portunidae			
Callinectes ornatus	9	4.7	5.0
C. sapidus	11	7.9	8.6
Portunus gibbesii	89	11.0	10.2
P. sayi	5	2.4	0.6
P. spp.	26	11.0	4.3
Unidentifiable portunids	36	18.1	3.0
Xanthidae			
Menippe mercenaria	1	0.8	0.2
Neopanope texana	2	1.6	0.3
Vertebrata			
Amphibia			
Ranidae			
Rana spp.	1	0.8	0.2
Osteichthyes			
Clupeidae			
Harengula pensacolae	1	0.8	0.2

Table XVI-7. Stomach contents of 271 adult snook, 127 of which contained food, from Ten Thousand Islands, Florida, May to August 1972. Continued.

Food Item	Numerical Total	Percent Frequency of Occurrence	Percent of Total Volume
Engraulidae			
Anchoa mitchilli	4	2.4	0.3
Synodidontidae			
Synodus foetens	1	0.8	0.5
Antherinidae			
Menidia beryllina	4	1.6	0.2
Cyprinodontidae			
Cyprinodon variegatus	1	0.8	<0.1
Floridicthys carpio	1	0.8	0.5
Poeciliidae			
Poecilia latipinna	1	0.8	<0.1
Centrarchidae			
Lepomis punctatus	2	0.8	3.4
Gerreidae			
Eucinostomus gula	1	0.8	1.0
Sparidae			
Lagodon rhomboides	5	2.4	5.3
Gobiidae			
Lophogobius cyprinoides	1	0.8	0.2
Unidentifiable fishes	71	38.6	43.3
Planta			
Algae			
Phaeophyta	2	0.8	<0.1
Vascular plants			
Diplanthera wrightii	11	3.1	0.3
Thalassia testudinum	1	0.8	0.2
Bivalve shell and coral fragments	18	7.9	1.1
SUMMARY			
Shrimps	98	35.4	9.6
Crabs	181	48.0	32.3
Other crustacea	2	1.6	1.1
Fishes	93	48.8	55.1
Other vertebrates	1	0.8	0.2
Plant material	14	4.7	0.6
Inorganic material	18	7.9	1.1

The dominant crustaceans in the stomach contents of the adults were crabs of the family Portunidae, composed of *Callinectes sapidus*, *C. ornatus*, *Portunus gibbesii*, and *P. sayi*. Mud crabs (Xanthidae), represented by *Menippe mercenaria* and *Neopanope texana*, and hermit crabs (Paguridae) formed minor components of the snook's diet. Portunids are swimming crabs that frequently inhabit pelagic zones, while xanthids and pagurids are generally associated with the benthos.

Of several shrimp species in the stomachs of adults, the pink shrimp (85 by number, 29.1 percent by occurrence, and 9.1 percent by volume) was the dominant organism. Other identifiable shrimps of minor importance as food included *Palaemonetes intermedius*, *Alpheus heterochaelis*, and *Hippolyte pleuracantha*.

Incidental food items occurring in the stomach contents of snook were a crayfish (*Procambarus alleni*), an isopod, and a tadpole (*Rana* sp.). Non-food items consisted of strands of algae and vascular plant material, pieces of bivalve shells, and coral fragments.

Harrington and Harrington (1961) provided the only known quantitative data on the food habits of juvenile *C. undecimalis*. They examined 172 snook, ranging in size from 5.3 to 51.3 mm FL, from a high salt marsh in northeast Florida during September and October. They reported that the smallest snook (5.3 to 16.8 mm) fed almost exclusively on copepods (cyclopoids, harpacticoids, and calanoids) with lesser amounts of mosquito larvae and fishes. Zooplankton comprised about 87 percent by volume of the food material in snook of this size range. In the 18.0 to 28.3 mm size group, fishes accounted for 85 percent of the total food volume, copepods for 13 percent, and grass shrimp (*Palaemonetes intermedius*) for 2 percent. Juveniles between 29.5 and 51.3 mm in length fed exclusively on fishes (89 percent) and *Palaemonetes* shrimp (11 percent). Unfortunately, they did not identify the species of forage fishes that the snook had preyed upon. The observations of Harrington and Harrington that juvenile snook initially fed on zooplankton, followed by a transitional shift (around 18.0 to 28.3 mm in length) to a piscivorous diet were in agreement with our study.

Qualitative studies on the food of juvenile snook included the investigation of Harrington and Harrington (1961) and Linton and Rickards (1965). The latter authors examined the stomach contents of 62 specimens (27.3 to 85.7 mm FL) from tidal creeks in Georgia. Food items were found in the stomachs of 24 snook. They reported that *Palaemonetes* shrimps accounted for 88 percent (frequency of occurrence) of the food and *Gambusia affinis* for the remainder. Their data were neither in agreement with Harrington and Harrington nor with the present study which demonstrated that juveniles within the above size range were predominantly piscivorous.

FOOD HABITS RELATED TO SIZE

Ontogenetic shifts in the food habits of the snook were evaluated by grouping the juveniles into 12 size classes between 11.0 and 200.0 mm in length and the adults into four size classes between 201 and 1,020 mm (Figure XVI-3). Juveniles of this species exhibited two distinct feeding stages: planktivorous and carnivorous. Numerous shifts in the contribution (by percent volume) of the major food items (fishes, shrimps, and crabs) were observed in the carnivorous diet of the larger juvenile and adult size classes.

Juveniles in the smallest size class (11.0 to 20.0 mm) were exclusively planktivorous, with copepods (Calanidae) and cladocerans accounting for all of

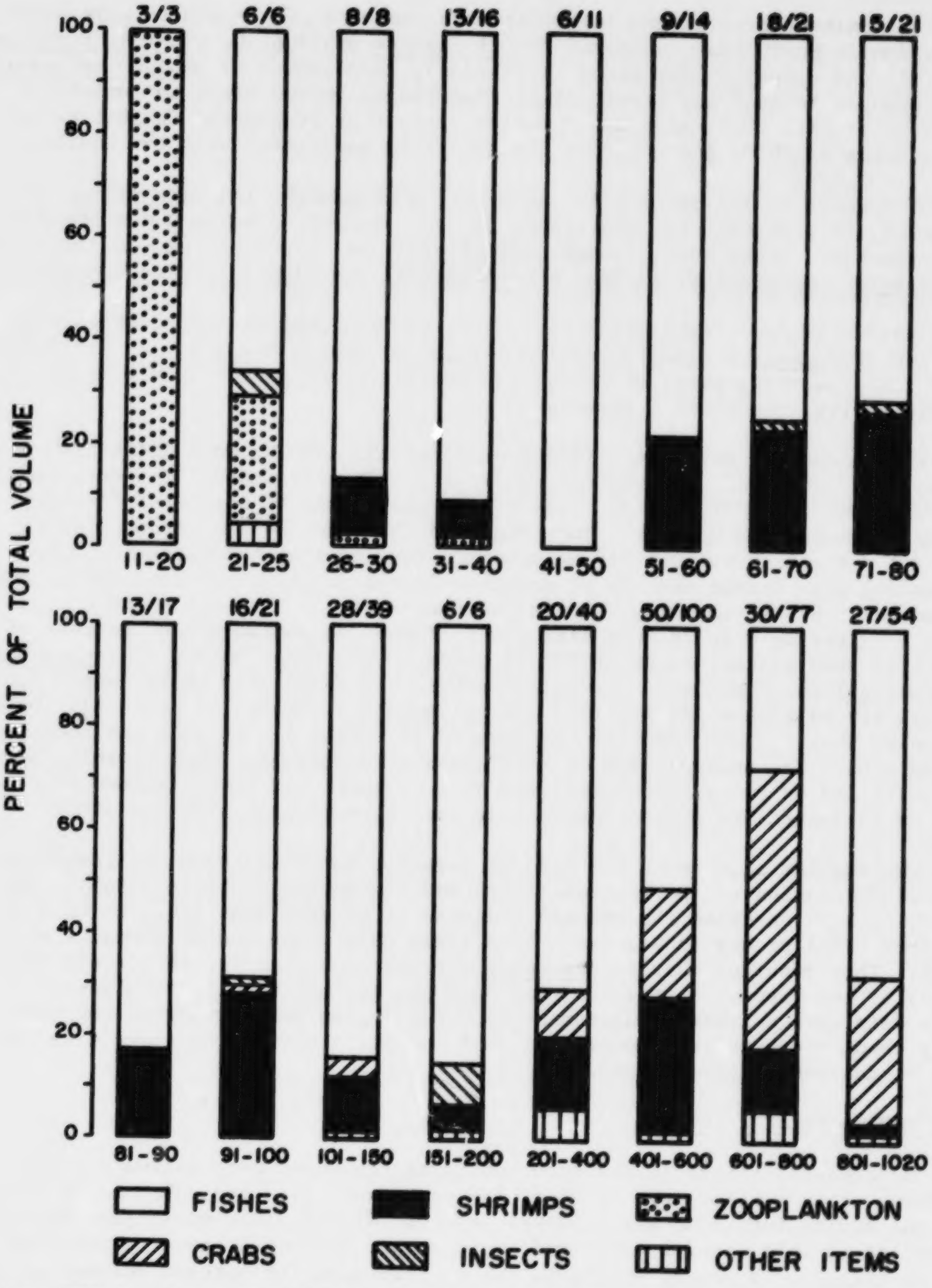

Figure XVI-3. Percent of total volume of major food items in the stomach contents of 173 juvenile (11-200 mm FL) and 271 adult (201-1,020 mm FL) snook collected in Ten Thousand Islands, Florida, 1972. Values above each histogram indicate the number of stomachs with food (numerator) over the total number of snook that were examined (denominator). Size class groups appear below each histogram.

the food material. A transitional period was apparent at a size of 21.0 to 25.0 mm in which juveniles became quite carnivorous (mainly piscivorous), consuming lesser quantities of zooplankton and a greater volume of fishes (Figure XVI-3). During this transitional period, a variety of food items were present in the juvenile diet. Microcrustaceans included copepods, ostracods, amphipods, and insect nymphs. In Figure XVI-3, amphipods were placed in the zooplankton fraction, since these immature specimens presumably occurred as suspended material in the tidal streams. The abruptness of the transitional feeding stage was indicated by the predominently carnivorous diet of the snook in the subsequent size class (26 to 30 mm), which was composed of fishes and palaemonid shrimp with only a trace of zooplankton. The initial forage fishes preyed upon by juveniles were Gambusia affinis and Cyprinodon variegatus.

As a function of growth, changes in the carnivorous diet of the juveniles were frequently related to the size of the prey. The larger sized fishes, such as adult Poecilia latipinna and Lophogobius cyprinoides, were eaten by juveniles over 100.0 mm in length, while smaller-sized fishes, such as Gambusia affinis and Menidia beryllina, were more frequently preyed upon by juveniles less than 100.0 mm. Also, the data revealed a change in emphasis in relation to the shrimps; the smaller palaemonid species were readily consumed by juveniles between 26.0 and 100.0 mm; whereas, larger penaeid shrimp formed the bulk of the diet of juveniles in 101.0 to 200.0 mm size classes.

Relative changes in the summer dietary habits of the adults were shown among the four size classes (Figure XVI-3). Fishes were the major food source in three of the four groups, ranging from 27.5 to 70.8 percent by volume. Crabs, mainly portunids, steadily increased in importance among the adults, reaching a peak abundance (54.7 percent) in 601.0 to 800.0 mm size class. Shrimps, primarily Penaeus duorarum, ranked third in importance (by volume) as food, but were essentially insignificant in the diet of adults in the 801.0 to 1,020.0 mm size class.

FEEDING HABITS

An inquiry into the feeding habits of juvenile and adult snook was based on the analyses of food habits (Table XVI-6 and 7) and on observations in nature. The preponderance of food organisms in the diet, e.g., calanoid copepods, cladocerans, swimming crabs (portunids), penaeid shrimp, and poecilid, atherinid, and sparid fishes, were associated either entirely or at least partially with some portion of the water column. Some animals, such as the pink shrimp and the blue crab, that burrow into the substrate are not exclusively benthic inhabitants, since they spend a portion of their time off the bottom. In addition, Darnell (1958) indicated that certain organisms (polychaetes, bivalve molluscs, hydroids, xanthid crabs, and isopods) and the presence of bottom material (sand grains, mud, and debris) were characteristic items in the stomach contents of benthic feeding fishes. These items were noticeably absent or if present, of minor importance in the dietary requirements of the snook. Thus, analysis of the data indicated that the snook is a pelagic feeder.

A periodicity in feeding intensity occurred in this species, which was realted to time of day, tidal flow, and habitat. Adults exhibited two peak feeding periods, as suggested by increased catches (hook-and-line) and by the condition of food in the stomachs. Feeding intensified in the early morning, specifically a couple of hours before sunrise, and in the early evening, two or three hours after sunset. Juvenile snook did not appear to conform to this pattern.

Minor periods of feeding intensity in adults were associated with changes in the tidal cycle. A feeding response was triggered, apparently by flowing waters, following a standing ebb or flood tide. A similar behavior was observed in the feeding of the larger juveniles.

The predominant feeding grounds of the adults were in narrow passes or cuts between islands during periods of strong currents. The vulnerability of fishes, crabs, and shrimps increased as these organisms were swept along in the flowing waters. Even under artificial lights, feeding was most intense when a current was present but generally ceased during periods of slack tide. The feeding of juveniles also intensified in moving waters, which may partially explain why the narrow confines of tidal streams served as a major habitat for the young.

XVII - WASTE INVENTORY

INTRODUCTION

The current waste treatment practices and disposal methods for southwest Florida were inventoried as a stated requirement of the South Florida Ecological Study. The area of consideration is generally defined as south of Lake Okeechobee and includes Charlotte, Glades, Hendry, Lee, Collier, Monroe, Dade, Broward, and Palm Beach Counties. The time budget of the study required that the scope of the inventory be limited to the southwesternmost counties contiguous with and north of the Big Cypress Swamp. These counties included Charlotte, Glades, Hendry, Lee, and Collier. Although the counties of Monroe, Dade, Broward, and Palm Beach were not inventoried, a catalog of inventories carried out by various groups over the past few years in these counties is presented in Appendix OO.

Southwest Florida, in particular Charlotte, Lee, and Collier Counties, is experiencing phenomenal increases in population growth. Obviously, demands for water and wastewater disposal are increasing proportionally and possibly at even greater rates. Wastewater disposal is of prime importance because fresh water is at a premium, groundwater is near the ground surface, and water percolates rapidly through the overlying sands to groundwater sources.

Current practices of scattered growth lead developers into using small package wastewater treatment plants. The cost of pumping sewage great distances into existing wastewater treatment plants if often prohibitive. As growth increases, so is the demand for more package plants, with an end result of many small plants serving an area which could be better served by one medium- to large-sized plant. Once a developer has made an investment in a treatment plant, it is extremely difficult to convince him to abandon this investment and to connect onto a central plant.

Although master planning is being carried out in these counties, the concept in many cases is following growth, not leading it. Even after sewage districts have been established, the pains and delays of bonding and achieving state and federal funding is often overwhelming.

METHODS

Information for this inventory was obtained from the files of the Florida Department of Pollution Control (DPC). The current practice of the DPC is to issue permits to construct and to operate wastewater treatment facilities. A registered engineer is required to sign these permits. In general, the permits are quite comprehensive and were certainly most ample for the limited amount of time that could be spent on the inventory. Treatment facilities not subject to the permit system are not contained in this report.

Domestic and industrial treatment plants were inventoried as to name, location, type of waste (industrial only), influent parameters (industrial only), population served (domestic only), average and design flows, percent removal of the influent concentrations, type of treatment, receiving stream, and receiving basin. The waste type was limited to the general categories of laundry waste, cooling water, dairy waste, etc. Influent parameters and flows were taken directly from the engineer's estimates contained in DPC permit system reports. Percent removal of influent parameters was derived from two sources. The first of these sources is a monthly operating report of each wastewater treatment plant required by the DPC. This report has no specific format and is basically a once-a-month log of 5-day biochemical oxygen demand (BOD_5) and suspended solids (SS) removals. The report is predicated upon the DPC requirement of 90-percent BOD_5 and 90-percent SS removals. Approximately 60 to 70 percent of the wastewater treatment plant owners were submitting this report to the DPC. If this report was not available, then the second source was, again, the permit system. BOD_5 and SS removals were than taken as the design engineer's estimate, if available, of the plant's efficiency.

Types of wastewater treatment are listed in general terms such as activated sludge (extended aeration, contact stabilization), trickling filters, and stabilization lagoons. Chlorination is also listed when it appeared on the permits.

Effluent discharge points are listed as drainfields (drain tile), specific and undefined streams, the Gulf of Mexico, total retention ponds, or surface irrigation.

The final inventoried parameter is the basin receiving the effluent. This information was compiled by following the water course of the receiving streams. In general, the ultimate basin is the Gulf of Mexico; but in order to be more specific, the basins listed are major rivers, passes, and harbors at the ocean frontage. Seven basins are listed along with undefined tidal canals and also on-site disposal.

RESULTS

The DPC permitting system has listed for the five counties of Charlotte, Collier, Glades, Hendry, and Lee a total of 309 wastewater treatment facilities, of which 265 were domestic waste plants (Appendix PP) and 44 were industrial waste treatment plants (Appendix QQ). The actual number of plants complying with the permitting system was unknown. Also, the DPC does not require a permit for domestic wastewater treatment plants that have a designed flow of less than 3,000 gallons per day (gpd).

Of the 309 listed wastewater treatment plants, 271 (or 87.7 percent) were of a design capacity of less than 50,000 gpd (Table XVII-1). Typically, the small plants are extended aeration "package" sewage treatment facilities.* When these plants reach or exceed their design capacity, they can be converted to a contact stabilization process which will approximately double the capacity of the extended aeration process (Figure XVII-1).

In the extended aeration mode, the plants can attain 90-percent BOD_5 and SS removals with a reasonable amount of operational control. However, when these plants are converted to a contact stabilization mode, greater control is required to maintain desired efficiencies of treatment. Frequently, the plants are operated by untrained personnel. Also presented in Table XVII-1 are the effluent discharge points.

* The designation "package" refers to prefabricated plants readily available from several vendors.

Table XVII-1. Wastewater treatment facilities in southwest Florida by county as of January 1, 1973.

County	Treatment Plants	Design Flow 50,000 GPD or Less	Effluent Discharge Point: Streams or Gulf	Drainfields	Total Retention Ponds	Surface Irrigation	Unknown
INDUSTRIAL WASTE							
Charlotte	5	5	2	-	-	1	2
Collier	15	15	1	3	5	2	4
Glades	4	2	1	-	1	-	2
Hendry	2	-	1	-	1	-	-
Lee	18	16	7	3	5	2	1
Sub total	44	38	12	6	12	5	9
DOMESTIC WASTE							
Charlotte	50	47	27	10	10	2	1
Collier	79	71	27	11	39	1	1
Glades	14	14	5	2	6	-	1
Hendry	10	8	3	1	5	1	-
Lee	112	93	17	31	51	7	6
Sub total	265	233	79	55	111	11	9
Total	309	271	91	61	123	16	18
Percentage of total	-	87.7	29.5	19.7	39.8	5.2	5.8

Total retention (evaporation/percolation) ponds are the most common disposal means, with 40 percent of the plants using this method. High evaporation and percolation rates make these ponds an acceptable method of effluent disposal. However, increasing land values in some areas may serve as a deterrent to implementation of such disposal methods.

Thirty percent of the treatment facilities discharge their effluent to streams or to the Gulf of Mexico. If operational control becomes lax or plant overloading takes place, this method of wastewater disposal may present a pollutional hazard to many public beaches and recreational areas. Ironically, the public beaches have their maximum use during the peak tourist season, at which time the greatest likelyhood of wastewater treatment plant overloading occurs.

Drainfields account for 20 percent of the effluent discharge points. The final method listed

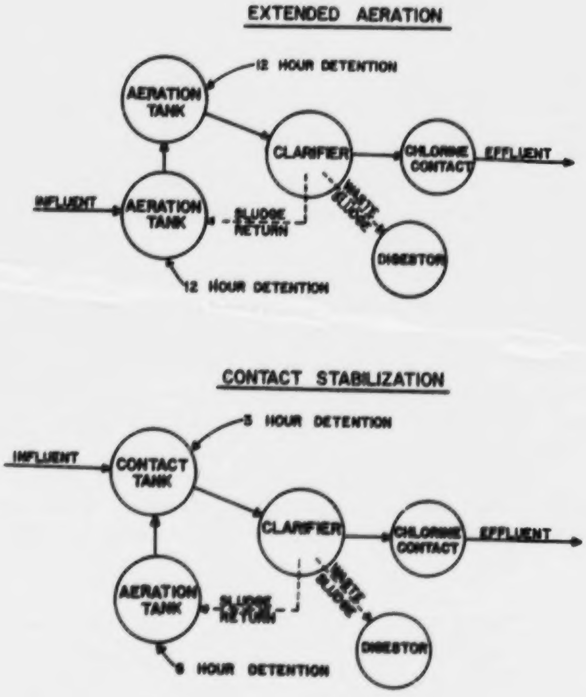
EXTENDED AERATION
12 HOUR DETENTION
AERATION TANK
CLARIFIER
CHLORINE CONTACT
EFFLUENT
INFLUENT
AERATION TANK
SLUDGE RETURN
WASTE SLUDGE
DIGESTOR
12 HOUR DETENTION
CONTACT STABILIZATION
3 HOUR DETENTION
INFLUENT
CONTACT TANK
CLARIFIER
CHLORINE CONTACT
EFFLUENT
AERATION TANK
SLUDGE RETURN
WASTE SLUDGE
DIGESTOR
6 HOUR DETENTION

Figure XVII-1. Schematic diatram of typical extended aeration and contact stabilization modes of "package" treatment plants.

is surface irrigation. Disposal by irrigation is used by 5 percent of the plants, with the typical disposal source being golf courses.

Seven basins (Figure XVII-2) in southwest Florida receive significant quantities of effluent discharge. These basins are Lake Okeechobee, Charlotte Harbor, Caloosahatchee River, Estero Bay, Naples Bay, Marco Pass, and Chokoloskee Pass (Table XVII-2). Tidal canals refers to undefined or minor tidal waterways. On-site disposal includes drainfield, evaporation-percolation ponds, and surface irrigation. Each basin is listed with the number of wastewater treatment plants (WTP) and their flows, in million gallons per day (mgd), discharging into them.

Table XVII-2. Receiving basins.

County	1 Lake Okeechobee		2 Charlotte Harbor		3 Caloosahatchee River		4 Estero Bay		5 Naples Bay		6 Marco Pass		7 Chokoloskee Pass		8 Tidal Canals		9 On Site Disposal	
	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)	No. of WTP	Flow (MGD)
INDUSTRIAL																		
Charlotte	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	1	0.012
Collier	-	-	-	-	-	-	-	-	-	-	-	-	1	0.010	-	-	8	0.086
Glades	1	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.050
Hendry	1	0.220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	3.000
Lee	-	-	-	-	5	*572.054	2	0.011	-	-	-	-	-	-	-	-	10	0.067
Subtotal	2	1.220	1	-	5	*572.054	2	0.011	-	-	-	-	1	0.010	1	-	21	3.215
DOMESTIC																		
Charlotte	-	-	26	2.438	-	-	-	-	-	-	-	-	-	-	1	0.015	22	0.283
Collier	-	-	-	-	-	-	-	-	9	2.945	3	0.029	2	0.115	15	0.281	49	1.416
Glades	3	0.028	-	-	-	-	-	-	-	-	-	-	-	-	2	0.038	8	0.122
Hendry	3	0.313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	0.137
Lee	-	-	-	-	13	11.933	4	0.060	-	-	-	-	-	-	-	-	89	3.473
Subtotal	6	0.341	26	2.438	13	11.933	4	0.060	9	2.945	3	0.029	2	0.115	18	0.334	175	5.431
TOTAL	8	1.561	27	2.438	18	*583.987	6	0.071	9	2.945	3	0.029	3	0.125	19	0.334	196	8.646

* Includes 571.4 MGD circulation of Caloosahatchee River for cooling water.

The basin, other than tidal canals or on-site disposal, receiving the largest number of waste treatment plant discharges is Charlotte Harbor. This harbor receives effluent from 27 plants which have a total design flow of 2.4 mdg. The Caloosahatchee River received the greatest wastewater flow (12.6 mgd not including cooling water discharge) from 18 plants.

On-site disposal is employed at two-thirds of the plants, not including one 3-mgd industrial waste plant. The average flow of these 195 plants, which use on-site disposal, is less than 30,000 mgd.

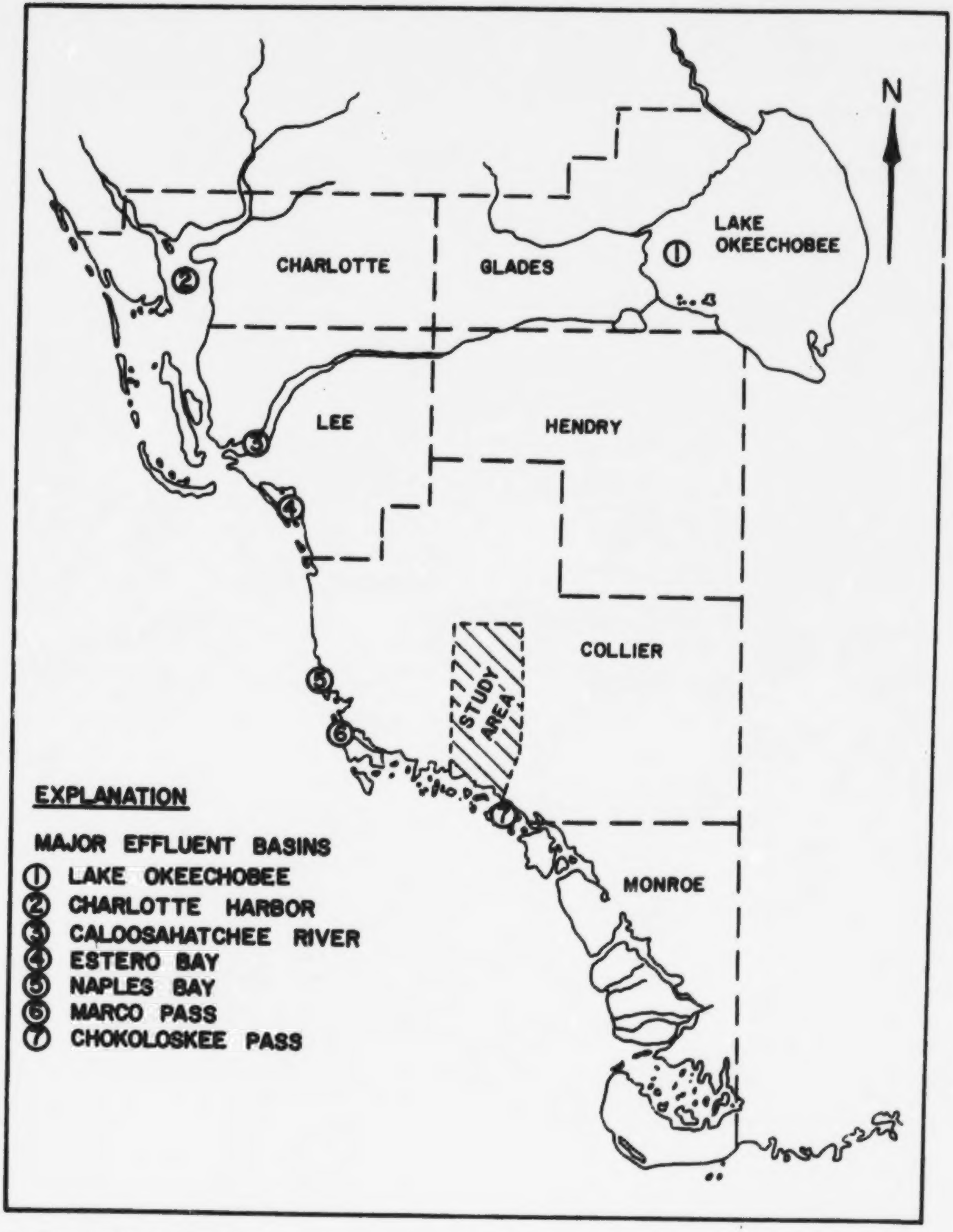
N
LAKE OKEECHOBEE
CHARLOTTE
GLADES
LEE
HENDRY
COLLIER
STUDY AREA
MONROE
① ② ③ ④ ⑤ ⑥ ⑦
EXPLANATION
MAJOR EFFLUENT BASINS
① LAKE OKEECHOBEE
② CHARLOTTE HARBOR
③ CALOOSAHATCHEE RIVER
④ ESTERO BAY
⑤ NAPLES BAY
⑥ MARCO PASS
⑦ CHOKOLOSKEE PASS

Figure XVII-2. Major wastewater effluent basins in southwest Florida.

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APPENDIX A - METHODS OF ECOSYSTEM ANALYSIS

The energy circuit language developed by H. T. Odum (Odum and Pinkerton 1955, Odum 1967a, 1967b, 1968, 1970, 1971, 1972) and concepts of systems ecology developed over the past several decades (e.g. Patten 1972 and contained references) by many investigators formed the methodological basis of our approach to the analysis of the Fahkahatchee ecosystem. In the following discussion we shall recapitulate a few of the main trends of this branch of ecology as a means of making our methodological biases explicit. Our additional goal here is to clarify the logic underlying the inferences we draw from the data concerning the overall structure and functioning of the Fahkahatchee ecosystem.

An ecosystem can be defined for analytical purposes as a set of functional components, biotic and abiotic, which are coupled by flows of energy and materials whose magnitude, direction, and functional form are amenable to direct investigation. Within this definition there is a major disparity between energetic coupling and mineral flow coupling that must be borne firmly in mind. It is summarized by the text book distinction that minerals circulate in ecosystems; but the flow of energy is one-way through the system. Incoming energy is ultimately dissipated in heat. A major area of investigation in systems ecology is embedded within this definition, that of the nature of the interaction between these two apparently dissimilar processes.

The flow of energy and materials in ecosystems is roughly parallel. For example, the transfer of energy along food chains occurs via the consumption of high-energy materials contained in the food. The concentration of mineral nutrients in the soil system is paralleled by a dissipation of energy in the detrital food chain. This interaction of energy flow and mineral cycling serves to organize collections of plant and animal populations into ecosystems: the population gene pools act as an information storage that establishes and maintains the range of successful interactions we see operating in ecosystems today.

Transformation of energy into useful work is the basic process governing the operation of all systems. Artificial systems serving man's purposes rely on the ingenuity of the engineer to establish useful pathways of energy flow, while natural systems enploy selective pressures acting over a lengthy time span to achieve what may be similar end results. These may include the development of processes that enhance long-term stability, some set of particular resource utilization rates with a balance of throughput and recycling, and progressively greater internal control of environmental variables. In both cases the laws of thermodynamics establish the boundary conditions that constrain system operation. These laws help form the underlying guidelines for constructing system circuit diagrams for ecosystem analysis.

In brief, the first (conservation) law imposes a requirement that the energy budget be balanced, i.e., it is not possible for any incoming energy to simply disappear. This is not so trivial a point as it appears, for it serves as a means of keeping track of the completeness of a system definition: if major terms of the energy budget do not appear in the model, this can be taken as an indication that the circuit is not yet complete. The degradation of potential energy to dispersed forms (second thermodynamics law) accompanies every energy transformation. This forces systems to treat the utilization of potential as a prime resource. Perhaps a profitable way of viewing the second (entropy) law in this context is that potential represents the opportunity to perform useful work, and some of this opportunity is irretrievably expended each time it is employed.

These two considerations make possible the calculation of balanced energy budgets for whole systems, and lend assurance that the opportunity to transform energy to useful work must be apportioned in a systematic, regular fashion. The loss of work opportunity with each transformation forces the system to treat this eminently exhaustible commodity as its most precious resource. Moreover, it assures us that there is scant likelihood that any substantial energy consuming process is incidental to basic system function.

Natural systems subsidize the operation of human systems in many ways. The subsidies range from the generation in past ages of the fossil fuels that power today's technological revolution to the provision of the multitude of services subsumed under the classical economic definition of a "free good". We must include in this category the esthetic and cultural values derived by the individual from recreational opportunities afforded by access to green space and wilderness.

Estimation of the value of these subsidies, and the development of means of interweaving the strands of the social and ecological fabric to enhance their mutual survival, are still in their infancy. Too often the valuation of natural systems is based merely on the dollar cost to man of operations that serve to exploit a resource. The primary expenditures of energy that originally produced and continually maintain the resource base are usually forgotten.

The circulation of mineral elements in ecosystems may act as a feedback governor that helps control the direction and speed of energy flow. A similar mechanism may be at work in economic systems, insofar as currency circulation may be said to effect changes in potential work opportunities. This feedback effect lets us define an energetic value for minerals and nutrients in terms of the energy flows they control. A similar treatment of dollar flow and energy flow may be possible as well. Dollar flow and mineral flow are in any case both accompaniments to the flow of energy and its dissipation in the course of the useful work that has developed and maintains the world as we know it. This parallelism allows preliminary comparisons of natural and artificial systems to be made in terms of a common measure of value. For example, a quantitative equivalence between currency and energy can be defined from a ratio of kilocalories of energy to the U. S. dollar, derivable from available information on the annual real gross national product and total yearly power consumption in the U. S. economy.

Photosynthesis, respiration, and matter transport are the basic processes of ecosystems that account for energy fixation, utilization, and transformation; and for the cycling of crucial limiting minerals. The primary productivity of the ecosystem represents the energy available to operate all the energy consuming processes and biological work powered by organic respiration throughout the system. For this reason primary consideration must be given to direct measurement of gross photosynthesis as a most important system parameter; for gross primary productivity establishes the magnitude of the organic energy budget available for all other purposes. Ecosystems may be coupled to auxiliary energy sources as well, and in some cases may be totally dependent on them (for example, benthic detrital systems). Auxilliary energy sources provided by physical and chemical environmental processes may reduce the quantities of energy the system expends in maintenance, and are often of sufficient magnitude to produce selective pressures that create ecosystems specifically adapted to utilize them. In general, these subsidies may make additional energies available for increased complexity of biological organization or increased net productivity. At the other end of the scale, physical processes often produce conditions that require a commitment of energy resources to counter destructive effects - this situation serves to define the concept of a "stress" in energetic terms.

A word is in order here concerning the modular components used in the energy circuit language for constructing compartmental models of ecosystems. A set of 15 basic symbols of this language is given in Figure A-1. Each module

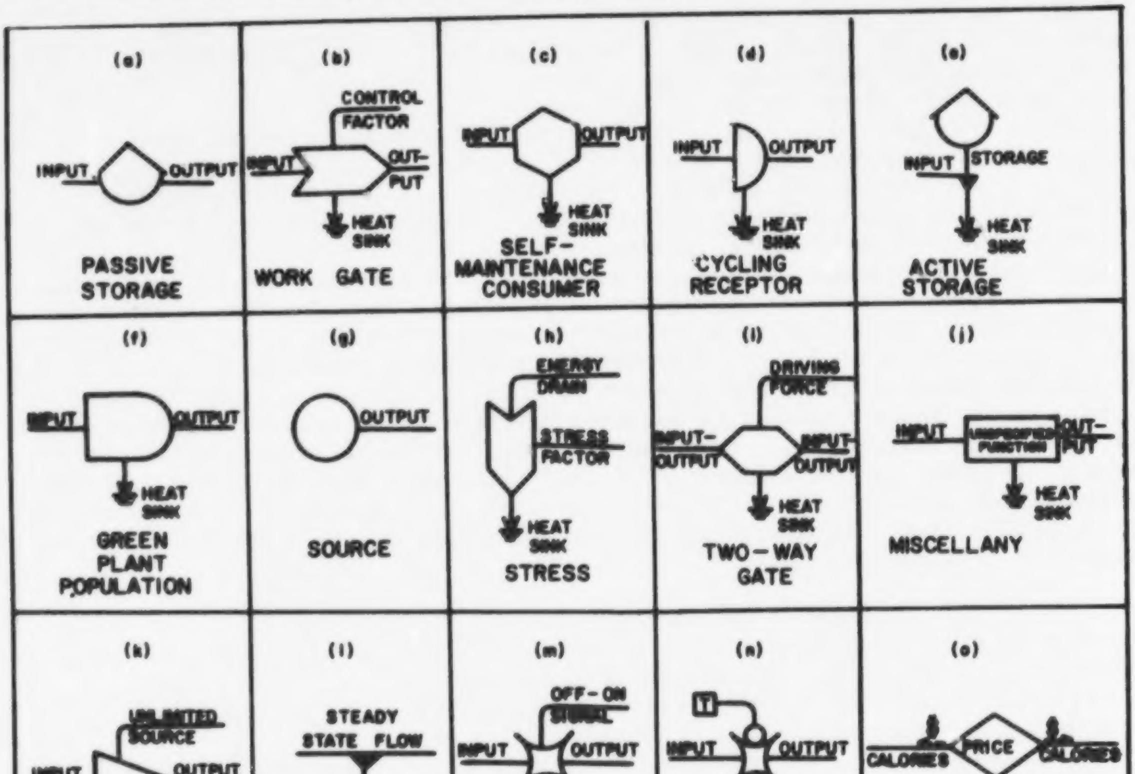
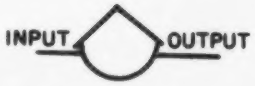

(a)
INPUT
OUTPUT
PASSIVE STORAGE
(b)
CONTROL FACTOR
INPUT
OUT-PUT
HEAT SINK
WORK GATE
(c)
INPUT
OUTPUT
HEAT SINK
SELF-MAINTENANCE CONSUMER
(d)
INPUT
OUTPUT
HEAT SINK
CYCLING RECEPTOR
(e)
INPUT
STORAGE
HEAT SINK
ACTIVE STORAGE
(f)
INPUT
OUTPUT
HEAT SINK
GREEN PLANT POPULATION
(g)
OUTPUT
SOURCE
(h)
ENERGY DRAIN
STRESS FACTOR
HEAT SINK
STRESS
(i)
DRIVING FORCE
INPUT-OUTPUT
INPUT-OUTPUT
HEAT SINK
TWO-WAY GATE
(j)
INPUT
UNSPECIFIED FUNCTION
OUT-PUT
HEAT SINK
MISCELLANY
(k)
UNLIMITED SOURCE
INPUT
OUTPUT
HEAT SINK
CONSTANT GAIN
(l)
STEADY STATE FLOW
HEAT SINK
PATHWAY HEAT SINK
(m)
OFF-ON SIGNAL
INPUT
OUTPUT
HEAT SINK
SWITCH CONTROL
(n)
T
INPUT
OUTPUT
HEAT SINK
THRESHOLD CONTROL
(o)
CALORIES
PRICE
CALORIES
HEAT SINK
ECONOMIC TRANSACTION

Figure A-1. Modules of the energy circuit language. These modules are used as block components in constructing compartmental models of ecosystems. Association of mathematical functions with compartment interactions leads to computer simulation of ecosystem dynamics. Details of these mathematical relationships and derivation of some interaction terms can be found in Odum (1972). Figure is redrawn from Lugo, et al. (1971).

represents a particular cluster of similar ecological entities, and each has a particular group of associated mathematical functions. Most basic ecological processes can be portrayed by combinations of these operators, which are defined as follows:

(a). The passive storage module stores potential energy as the balance of its inputs and outputs. A complete definition requires a mathematical expression for the quantity of potential energy stored, and an expression of storage functions for establishing that quantity. The expression for the outflow usually is a function of the circuit connections as well as the quantity stored, that is, the flow of energy from the storage will depend on the process to which it is coupled. The input functions may also be of several kinds. For example, water stored in a tank against gravity has an energetic value related to its hydrostatic head; energy in compressed gas is related to pressure by a logarithmic function. These storages are state variables of the system, and may represent storages of water, chemicals, biological populations, air, money, information, etc. In an environmental system, with its great diversity of possible utilization pathways, there are losses inherent in any storage. Almost any concentration of a quantity constitutes an incipient energy source by virtue of its low entropy, and tends to be used by one agency or another. For example, a storage of food tends to develop chemical reactions, populations of consumer insects, etc. Work is done to protect the source if containers or some other means are used to insulate an energy source from losses. This is, in effect, a drain on the source. Leaf litter dynamics in forest ecosystems is an example of a process describable by this module. The input to forest floor litter accumulation, a storage, is given by the simple sum of leaf-fall rates from the trees. Litter decomposition dynamics are adequately described by a rate equation based on the quantity of litter available to decomposer populations (see Chapter XII for an example of this application).

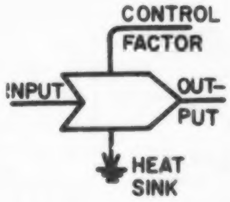
(a)



PASSIVE STORAGE

(b). The "work gate" represents a control function on the transmission characteristics of pathways of energy flow. The action of the control factor modifies the input-output transfer of energy through the block by regulating the conductivity of the contained pathway. For example, the transport rate of carbon dioxide gas to plants from atmospheric reservoirs is strongly controlled by wind driven air circulation in the forest. If the control agent is in short supply, the controlling factor can be represented as a passive storage. The dynamic behavior of the work-gate module can be shown to be a limiting factor hyperbola under these conditions (Odum, 1968). For example, photosynthetic production under phosphorus-limited conditions is controlled by the rate of supply of phosphorus to the plant community. Phosphorus supply may be governed by the rates of accretion from exogenous sources or in situ recycling of previously generated materials.

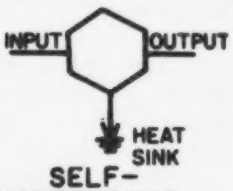
(b)



WORK GATE

(c) The "self maintaining consumer population" symbol representa a combination of "active storage" (Figure e) and a work-gate (Figure b). In the population module, potential energy stored within the population is utilized to maintain a continuing input of new potential for growth and reproduction. Several formulations of the detailed operation of this module lead naturally to mathematical functions that exhibit "logistic" properties, i.e. populations that grow rapidly at first and subsequently reach a stable plateau of population size.

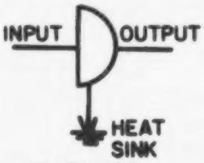
(c)



SELF-MAINTENANCE CONSUMER

(d) The "pure energy receptor" symbol represents a coupling of pure energies such as sound, light, and water wave trains to an energy storage process. Chlorophyll dynamics are an example of this process. In this module incoming energy interacts with some cycling material to produce an excited or activated state, which then decays to its ground state while transferring energy to the next step in a chain of linked reactions. The kinetics of this module were first described in terms of enzyme-catalyzed biochemical reactions, and is generally labelled "Michaelis-Mentor" kinetics. Its transfer function is hyperbolic. It is usually used in the present ecological context to depict the reception of light energy by plants in the initial steps of the photosynthetic reaction. Stable whole ecosystems whose mineral cycles are fully isolated from allocthonous interchange exhibit dynamic properties and a functional organization that can be described with this module (Odum, Lugo, and Burns, 1970).

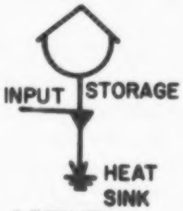
(d)



CYCLING RECEPTOR

(e) This "active storage" module expresses the generation of stored potential from an input energy flow. In this case the re-storage requires that some transformation process be performed on the input stream. In this module work is being done against some resisting force, and the potential may be stored in a new form. For example, conversion of the kinetic energy of falling water to electric power in hydroelectric engineering projects can be represented as an active storage. The law of entropy requires that such conversions cannot be 100 percent efficient, thus some of the input energy is necessarily diverted to the "heat sink" of the module.

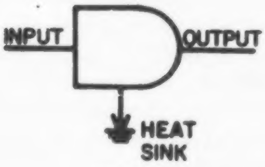
(e)



ACTIVE STORAGE

(f) The symbol for a plant population combines a cycling receptor module (Figure d) and self maintaining properties (Figure c). In addition, work must be done to maintain the photosynthetic machinery of the cycling receptor. All this internal organization is summarized in the bullet-shaped symbol of Figure f.

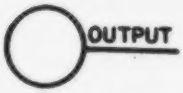
(f)



GREEN PLANT POPULATION

(g) Energy sources from outside the boundaries of the system of interest are indicated with a circle symbol. Names for this type of module from other system languages include: forcing function, driving function, environmental variable, etc. In order to completely describe the source, the nature of the energy flow (whether light, a flow of organic matter, the drying power of an air mass, etc.), and the manner of its delivery, must be specified. For example, one class of sources exert a constant driving tendency even when large flows are being delivered, e.g. the pressure from large water reservoirs, or chemical reactions taking place under conditions where reactant concentrations are maintained at constant levels. Another class is sources that deliver a constant flow regardless of the utilization pattern downstream. Examples include the flux of sunlight, and water flowing past a waterwheel. Whatever the case, the delivery function must be indicated mathematically or graphically to complete the description of the source.

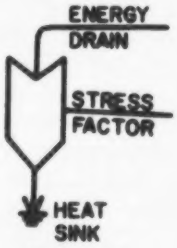
(g)



SOURCE

(h) Stress factors require the commitment of metabolic energies to counter their destructive effects. This symbol summarizes the process as a drain of potential that would otherwise be available for other ecological purposes. Although the rate of energy drain may be a linear function of stress intensity, the response of the system to long-term stress may show a lengthy period of minimal effect followed by an abrupt collapse. Such a pattern could emerge from the gradual exhaustion of energy reserves used in the ecosystem to weather normal intermittent short periods of unfavorable environmental conditions, such as drought. The cruve for a stress factor might then follow the hyperbolic relationship of a limiting-factor work-gate, but in the opposite sense. The "stress" symbol, then, is an inverted work-gate draining system potential to the heat sink. The loss rate is controlled by an environmental factor entered on the opposite side of the gate.

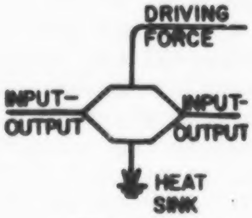
(h)



STRESS

(i) The "two-way gate" or forced diffusion module portrays a bi-directional transport of materials that may be proportional to a concentration gradient or a casual force operating the gate. The heat sink allows for conformance of the process to the second law of thermodynamics. Tidal flushing of an estuary is an example of such a process. Tidal forces move water in and out of the bay, and net concentration changes in dissolved materials are a function of concentration differences between estuarine and off-shore waters.

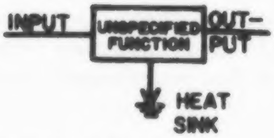
(i)



TWO-WAY GATE

(j) Any miscellaneous transfer function appropriate to special cases is represented with this box symbol. This module is used when the function is unknown or of no consequence to the point being made. It can also be used when the mathematical transfer function is known but a specific symbol is not available.

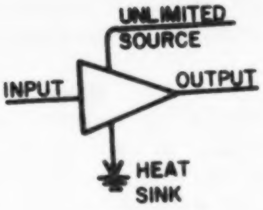
(j)



MISCELLANY

(k) In a "constant gain" amplifier the input force acts as a tap on an unlimited supply source. Output dynamics are expressed as a constant increment of the input force called the "gain" of the module. The exponential growth of biological populations under completely unlimiting conditions can be portrayed with this module.

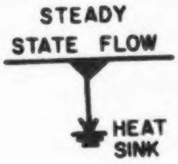
(k)



CONSTANT GAIN

(l) Pathways of energy delivery are represented by the interconnecting lines of the circuit diagram. The existence of the pathway generally implies that work is done to maintain it, and this must be shown somewhere in the diagram. The nature of the casual force producing the energy flow is not automatically defined by the pathway. As in the case of the energy source, additional notation must be added to define the transmission characteristics of the pathway. However, this question need not be explored if the coupled responses of the driving agent (source) and the module receiving the energy are known. For example, in creating sets of differential equations from a circuit diagram for simulation, the time dependent behavior of each module is frequently derived by writing expressions for the balance of inflows and outflows to the unit. Each algebraic term describes a flow as a function of the causal actions.

(l)



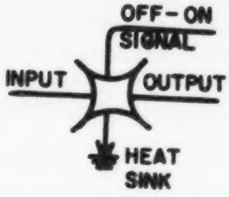
PATHWAY HEAT SINK

The second energy principle requires that all spontaneous processes include a dispersal of potential energy into distributed heat of the environment, unavailable as a driving impetus for any further process. The heat sink representing this must flow from every spontaneously operating module of the energy system. When some simple system such as water flow or electrical current flow is being represented, the heat sink receives flows directly from the pathway. In complex modules that represent groups of processes, the heat sink is a miscellaneous conduit of heat dispersal from the several processes. For example, the respiration of an organism is the sum of many processes of work and heat dispersal. Respiration can be measured by the oxygen consumption or CO_2 production that accompanies these processes. Measurement of total energy dissipation can be a good starting point in evaluating the energy flows of complex systems.

Particular component processes, whenever they are of interest, may be isolated, labelled, measured, and represented by separate flow lines and heat sinks. If the magnitude of the total process is known, this leaves, by substraction, a lesser flux of heat dispersal represented by the main miscellaneous heat flow of the module.

(m) The "switch control" symbol, a special case of work-gate, is used when discontinuities have been identified in a conductivity control process. The design of complex switching functions used in modern highspeed digital computers has provided a thorough theoretical background to the use of this module in ecological models. Some switched responses are of a simple on-off character, but many reflect the simultaneous presence of several necessary conditions for the initiation of an ecological process.

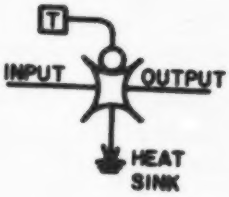
(m)



SWITCH CONTROL

(n) Many responses of ecosystems to environmental variables involve threshold effects. For example, the light ground fires characteristic of many southeastern ecosystems will not propagate unless standing stock of dry ground litter is greater than some threshold level (T). The small circle symbol represents a logical "not" operation by which cutoff points can be represented by this module. It portrays a flow of energy that abruptly ceases when some control threshold is exceeded.

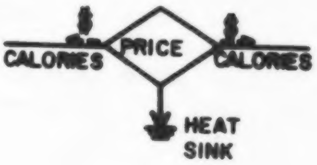
(n)



THRESHOLD CONTROL

(o) The "economic transactor" is used to relate the flow of energy to the flow of money, both in economic systems and at the interface between economic and ecological systems. Unlike the flow of minerals that accompanies energy flow, the parallel flow of money is in the opposite direction, as in a grocery store. The price structure and market mechanisms of the economic system regulates the conductivity and kinetics of this module. The direct heat losses of these transactions are small since the work involved generally is small, as for example in the purchase of goods in a market. However, the maintenance of complex regulatory agencies for controlling the prices of goods and services may induce substantial costs of coupling within the system.

(o)



ECONOMIC TRANSACTION

We can summarize the useful features of the energy circuit language for compartmental modeling of ecological systems as follows:

1. Information is presented in a diagrammatic form that conveniently summarizes large quantities of data.

2. Energy flow pathways and functional interactions are presented in an explicit form.

3. Energy circuits can be rapidly transferred to a set of mathematical equations for simulation.

4. Each module implies a particular type of process describable by one of a limited set of mathematical functions.

5. Research directed toward calibration of the model and calculation of necessary coefficients for simulation can be coordinated by referring to the diagrams.

APPENDIX B - ECOSYSTEMS MODELS

This appendix contains models of 5 ecosystem types that are common in the Fahkahatchee area: shallow estuarine ecosystems, mangroves, wet prairie, cypress, and pineland. It is reprinted (retyped) from: Lugo, A. E., S. C. Snedaker, S. Bayley, and H. T. Odum, 1971. Models for planning and research for the South Florida Environmental Study. University of Florida, Gainesville. 123 pp.

Shallow Estuarine Ecosystems - Three types: marine meadows, hypersaline lagoons, and estuaries enriched with municipal wastes.

In Figure (11) are diagrammed some of the main parts and processes of shallow estuarine ecosystems. In clear shallow waters with good water movement, the bottom plants dominate and the marine meadow system results. When evaporation exceeds freshwater inflows, salinities rise above that of the open sea (36 ppt) causing a decrease in diversities of many species: this is the hypersaline ecosystem type. When enriched with municipal wastes containing fertilizer elements from treated sewage, phytoplankton growths predominate, shading out many bottom plants, producing some oxygen extremes and other properties associated with the concept of eutrophication. The diagram becomes modified in various ways for the various kinds of shallow estuaries of south Florida depending on which pathways are the most important.

In the estuarine model (Figure 11), the sources of the forcing functions are shown to be: tides, winds, nutrient and toxic wastes, sunlight, air, dry air, river water and rain, human and bird population, saltwater and fisherman. The natural forces all interact among themselves and with the biota to maintain a highly productive system. Since estuarine ecosystems are so strongly coupled to many other systems their values have not been understood and they have become one of the most abused ecosystems.

Phytoplankton and bottom meadows, consisting of submerged macrophytic aquatic plants are shown as the major producers. The red tide is also shown as a producer population even though its role in the system is not completely understood. As discussed previously its role could be related to acute eutrophication. Because of its severe ecological and economic impact, it deserves intensive study.

The interactions among the physical and chemical forces and the biotic components are the primary features of estuarine systems. An attempt has been made to diagram some of the interactions utilizing one-way and two-way workgates, energy sources and storages. For example, tide is illustrated as a major source of (1) motion (a storage symbol), (2) diffusion of oxygen and carbon dioxide between air and water (aided by wind), (3) generation of currents and internal mixing, and (4) movement of saltwater into the system. Tidal motions are also shown to be responsible for the redistribution of nutrients in river, sea and rain water and nutrient wastes, and then acting as an amplifier on plant

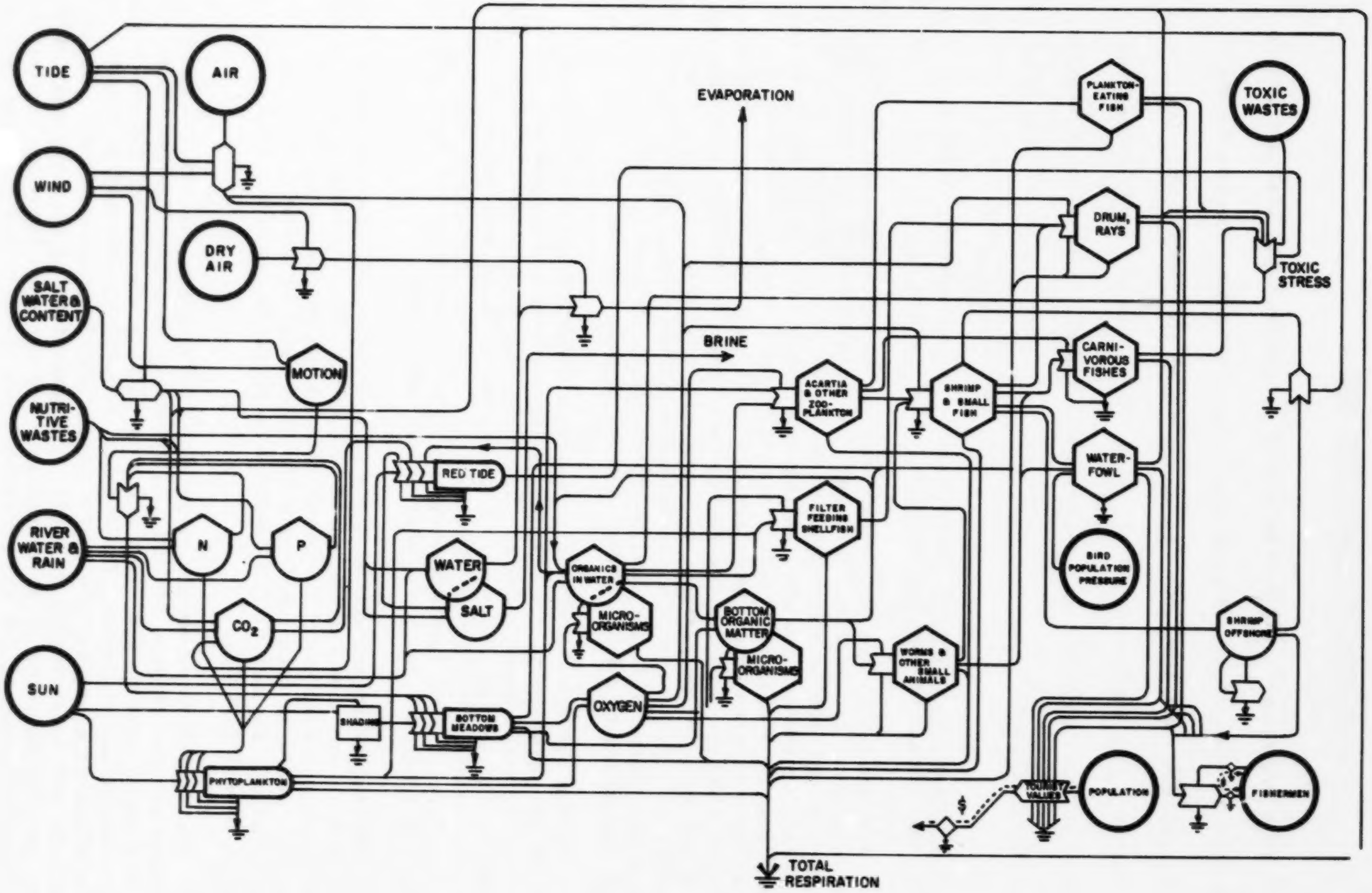

TIDE
AIR
WIND
DRY AIR
SALT WATER & CONTENT
MOTION
NUTRI-TIVE WASTES
RIVER WATER & RAIN
SUN
N
P
CO$_2$
SHADING
PHYTOPLANKTON
RED TIDE
WATER
SALT
BOTTOM MEADOWS
EVAPORATION
BRINE
ORGANICS IN WATER
MICRO-ORGANISMS
OXYGEN
BOTTOM ORGANIC MATTER
MICRO-ORGANISMS
ACARTIA & OTHER ZOO-PLANKTON
FILTER FEEDING SHELLFISH
WORMS & OTHER SMALL ANIMALS
SHRIMP & SMALL FISH
PLANKTON-EATING FISH
DRUM, RAYS
CARNI-VOROUS FISHES
WATER-FOWL
BIRD POPULATION PRESSURE
TOXIC WASTES
TOXIC STRESS
SHRIMP OFFSHORE
TOURIST VALUES
POPULATION
FISHERMEN
$
TOTAL RESPIRATION

Figure 11. Estuary including eutrophic and hypersaline types.

productivity. In addition to its contribution of nutrients, sea water is also shown to interact with dry air (air with a high saturation deficit) and wind which through evaporation increases salinity and may produce brine if dilution is prevented. Salinity differences also affect water currents and red tide.

The metabolic gases, oxygen and carbon dioxide, products of photosynthesis and respiration, respectively, are shown resulting directly from biological processes and indirectly as a result of diffusion. The whole system's respiratory carbon dioxide is shown as a multiplier on photosynthesis and the oxygen thus produced as a multiplier on all consumers. (For simplicity we have omitted several multipliers.) The importance of motion as a gas transport mechanism is also shown to have amplifier effect.

When an interaction function is unknown or unspecified, a box symbol is sometimes used. In this example, phytoplankton are shown shading the bottom meadows. Phytoplankton also support a portion of the food web by direct feeding and through the production of detrital organic material. Microbial decomposition converts this material for subsequent use in the filter feeder chain. Bottom meadows also generate organic material used in the food web.

From these diverse food chains, many species of game and commercial fish are derived. As shown in the model many, like the shrimp depend on water currents and outside sources of larvae for their residence in the estuarine system. Waterfowl are also shown to have an outside source of individuals through migration. In both cases, the organisms return to the open sea or terrestrial environments after completion of a portion of their life cycles in the estuary.

Because of the many gradients of stress already present in the estuary, and the demonstrated capacity of these organisms to concentrate different kinds of abiotic substances, addition of toxic substance to this ecosystem stress many of the component populations. This is shown in the model with the stress symbol, operated by toxic wastes, acting on many species of consumers. Man is shown, through his economic system, to derive a harvest of fishes and shrimp. Tourists values are also gained in proportion to population pressure.

Mangrove

Low-energy coastlines are characterized by bays, estuaries, salt and mud flats, salt marshes and mangrove swamps as opposed to the high-energy coastlines of sand beaches and dunes. The majority of south Florida's perimeter is composed of a wide band of mangroves juxtaposed between shallow estuaries and bays, and the upland land mass. Mangroves are a dominent natural feature due to the flat, slightly sloping relief of the south Florida peninsula. Unlike many of the other subsystems, the mangroves have clearly defined roles in the ecology of south Florida. Their ecological importance, however, is rarely taken into consideration by planners and developers who tend to view this land area as of marginal value and evaluate it in terms of human use and occupation. Some 400,000 acres of red mangroves have been so converted to other uses in Florida. The natural, regional roles of mangrove ecosystems are summarized within the following statements:

(1) Mangrove ecosystems intercept and filter surface water runoff thereby preventing large-scale nutrient losses to the open sea. A by-product of this filtering action is the maintenance of water quality.

(2) Their complex root structure serves in the accumulation of organic and inorganic materials. The systems also act as mechanical energy buffers to strong winds and storm tides, and thus prevent periodic devastations of the coastline.

(3) They have a high rate of leaf net-production (13 metric tons per hectare per year, Heald, 1970) which is largely exported into the estuaries and forms the basis of detrital food chains. This net production can also be evaluated in terms of the fisheries it supports.

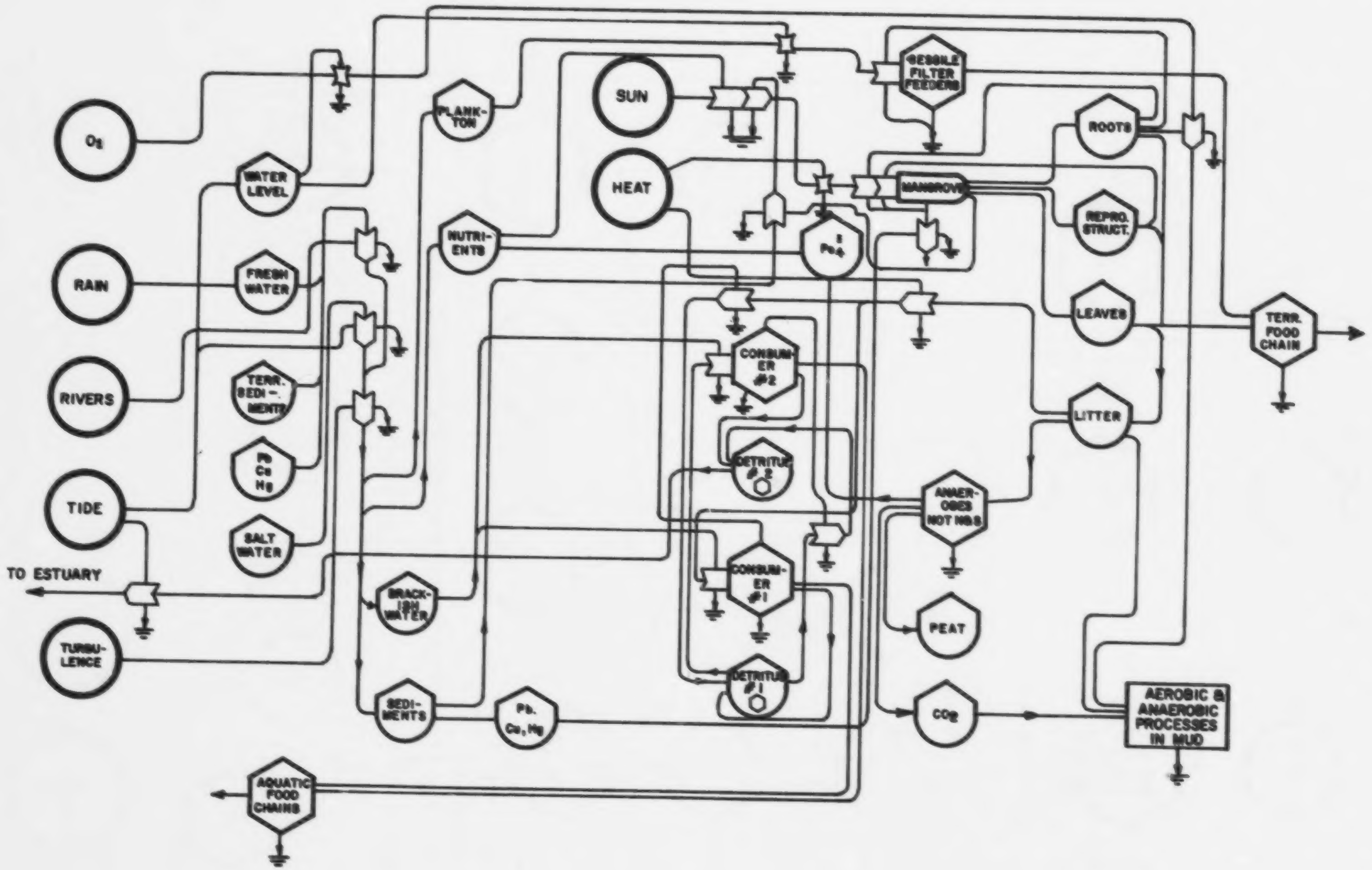
(4) The shallow waters around mangroves providing breeding and feeding areas for many estuarine dependent fisheries.

(5) Mangroves support large bird populations by providing rookeries adjacent to productive estuarine feeding areas.

Classical mono-specific mangrove ecosystems are composed of three dominant species whose locational relationships are closely correlated with salinity and topographic relief. The Red Mangrove (*Rhizophora mangle*)forms the outermost band associated with the lowest elevations and highest salinity. It is characterized by extensive prop roots. Inward from the Red Mangrove is the Black Mangrove (*Avicennia nitida*) growing at higher elevations which are subjected to smaller diurnal tidal variations. The Black Mangrove is characterized by pneumatophores which are suggested to have functions analogous to prop roots. The last landward zone is influenced only by maximum-high and storm tides and is composed of the White Mangrove (*Laguncularia racemosa*) and Buttonwood (*Conocarpus* sp.) in varying proportions. Mangroves, world wide, have been extensively studied, but only a very few of these investigations have attempted to quantitatively describe their structure and function. The most significant works are those of Davis (1940), Golley, Odum and Wilson (1962), Heald (1970), W. E. Odum (1970) and Golley, *et al*. (1968).

The energy sources powering the mangrove complex, modeled in Figure (14), are: oxygen, rain, river flow, tides, mixing action, sunlight and heat. The importance of oxygen as an energy source is shown by its effect in driving the many respiratory processes in the substrate of the mangroves which are limited by low oxygen concentrations. In the absence of oxygen the organic muds become anaerobic as shown in the submodel describing anaerobic processes (Figure 15). In addition, oxygen is required to sustain root respiration. Because of the limited amount of oxygen, roots are shown pumping oxygen into the sediments. Structurally this pumping is done via pneumatophores, lenticels, and diffusion through aerenchyma cells.

Rain is a source of freshwater into the system. Freshwater is shown to flow by the action of rivers and to become loaded with terrestrially-derived sediments and man-introduced substances such as heavy metals. In the mangrove areas, freshwater combines with saltwater and by the action of vigorous mixing, form brackish waters rich in nutrients which support a spectrum of organisms. The brackish waters are shown to act as a multiplier function on the energy



O2
RAIN
RIVERS
TIDE
TO ESTUARY
TURBU-LENCE
WATER LEVEL
FRESH WATER
TERR. SEDI-MENTS
Pb Cu Hg
SALT WATER
PLANK-TON
NUTRI-ENTS
BRACK-ISH WATER
SEDI-MENTS
Pb. Cu, Hg
AQUATIC FOOD CHAINS
SUN
HEAT
PO4
CONSUM-ER #2
DETRITUS #2
CONSUM-ER #1
DETRITUS #1
SESSILE FILTER FEEDERS
MANGROVE
ROOTS
REPRO. STRUCT.
LEAVES
LITTER
ANAER-OBES NOT H2S
PEAT
CO2
AEROBIC & ANAEROBIC PROCESSES IN MUD
TERR. FOOD CHAIN

Figure 14. Mangroves.

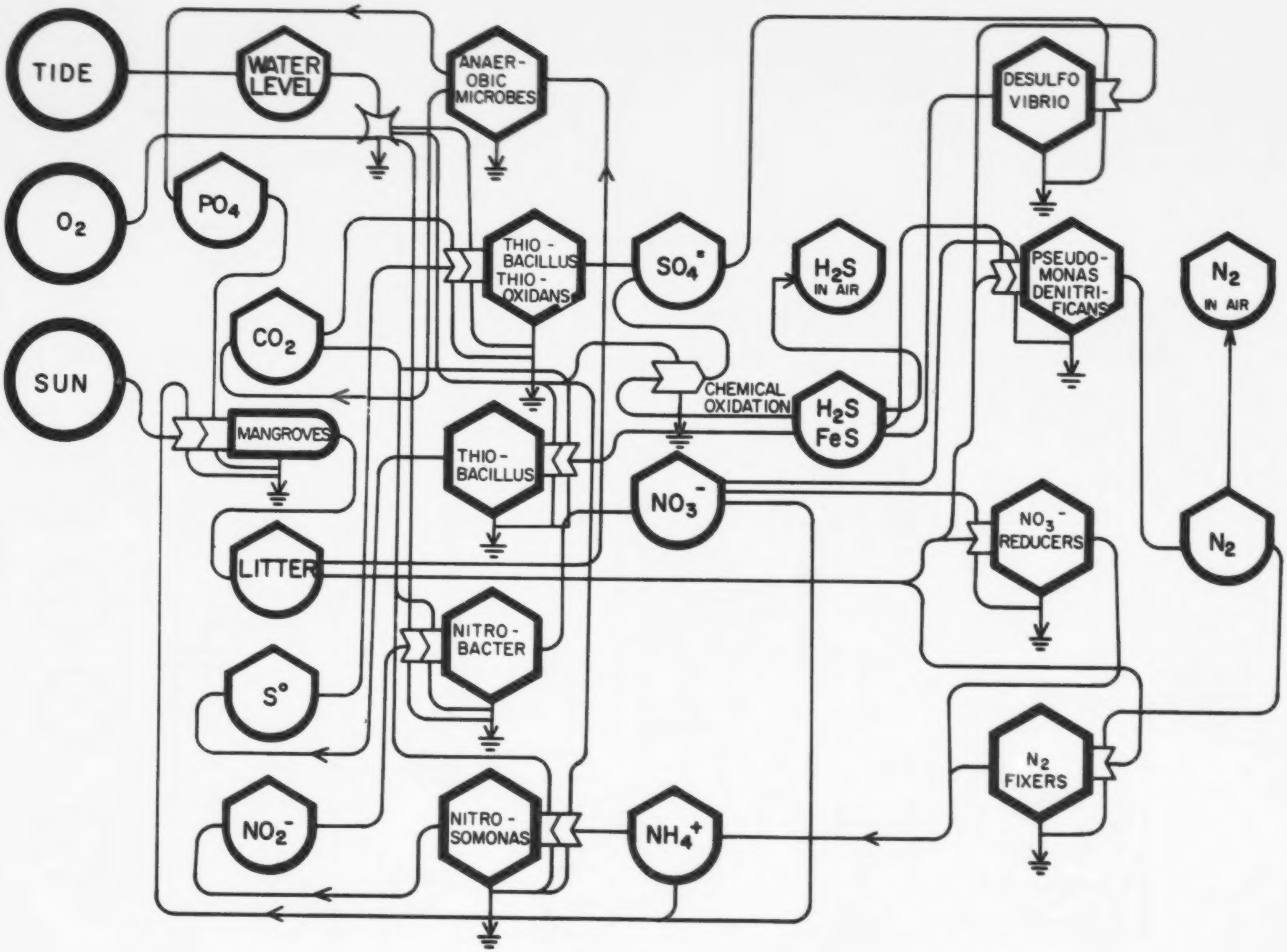

TIDE
WATER LEVEL
ANAEROBIC MICROBES
O_2
PO_4
SUN
CO_2
MANGROVES
LITTER
S°
NO_2^-
THIO-BACILLUS THIO-OXIDANS
THIO-BACILLUS
NITRO-BACTER
NITRO-SOMONAS
$SO_4^=$
CHEMICAL OXIDATION
NO_3^-
NH_4^+
H_2S IN AIR
H_2S FeS
DESULFO VIBRIO
PSEUDO-MONAS DENITRI-FICANS
NO_3^- REDUCERS
N_2 FIXERS
N_2 IN AIR
N_2

Figure 15. Aerobic and anaerobic processes in mud.

flows to those consumers adapted to the specific conditions associated with mangroves. Heald for example (1970) has shown that certain detritus decomposers function at faster rates in brackish waters in contrast to either saline or freshwaters. In the model, brackish waters are also shown to import nutrients which in turn act as multipliers on plant photosynthesis; they transport seston which are the base of a filter-feeder chain and are also shown to import the extraneous materials which may stress mangrove trees. They also provide sediments which affect plant zonation and in turn exert an influence on plant photosynthesis.

Tides are shown as an important source of energy in transporting waters and minerals in the estuarine-mangrove complex. For example, the model shows the tides serving as a "pump" of detrital particles from the mangroves to the estuaries. Another important role is the maintenance of the water level in the mangrove system. The water level is also shown to have a switching effect on the amount of oxygen available for respiratory processes in the sediments.

Solar energy is shown powering plant photosynthesis and the mangrove trees are depicted subdivided into their basic functional parts. Reproductive structures are shown as providing a feedback into productivity by maintaining a vigorous plant population. Roots are shown as important in pumping atmospheric oxygen into the sediments, and as a multiplier on sessile organisms which use them as a substrate. They also serve as multipliers on the trees themselves by their role in anchorage. Both roots and leaves contribute to the liter which in turn serves as a supplier of organic matter for sediment respiratory processes, peat formation, and as a base for decomposer and detrital food chains. Leaves, in addition, serve as a base for the grazer food chain which links the mangroves to the terrestrial ecosystem. The organisms in the terrestrial food chain also feed on sessile organisms on mangrove roots as shown in the model. The sessile organism exhibit an On-Off activity cycle determined by water-level fluctuations.

Aquatic food chains, both aerobic and anaerobic, are shown as being dependent on the detritus and sediments of the system. These two distinct processes are indicated in the diagram. In the detritus food chains, one consumer is shown doing work for the next by breaking up the detrital particles into smaller pieces and thus facilitating feeding. As the detrital particles are reduced in size due to decomposition and fragmentation by consumers, nutrients are released and incorporated into the system through plant photosynthesis. A multiplier on the mangroves illustrates this effect.

Heat is shown as an On-Off swtich on many of the metabolic processes of the system since they are sensitive to low temperatures which periodically stress these systems.

The sediments of mangrove systems, with their extensive organic matter storages and oxygen requirements, are complex biological networks where aerobic and anaerobic processes switch on and off depending on the particular environmental circumstances. The details of these processes are far from being completely understood and are perhaps one of the most exciting frontiers of ecology. In Figure (15) we have modeled some of the anaerobic and aerobic processes expected to occur in these muds. On the right side of the diagram, reduced compounds are shown as a storage being acted upon by self-maintaining organism populations. On the left, oxygen is shown as an energy source powering the oxidation of reduced compounds. This is illustrated as a multiplier on the aerobic-sediment flora. Note that $SO_4^=$, H_2S, FeS,NO_3^- and NH_4^+ couple the aerobic and anaerobic processes through their roles as the products and raw materials of various bacterial metabolic processes. Other details of the system's function are shown as they relate to the mangrove system. Illustrated are liter as a carbon source to the sediments and $PO_4^=$ production from anaerobic decomposition acting as a multiplier on plant productivity as does NO_3^-. The roles of CO_2, tides and water level in the system are also depicted.

Wet Prairie

Wet prairies are frequently designated to be those areas composed of *Rhynchospora*, *Eleocharis*, and *Panicum* and are characterized by water regimes which are intermediate between the sawgrass and slough ecosystems. In addition, this ecosystem is frequently found on a marl soil as compared with the peaty soils of sawgrass and slough ecosystems. Descriptions of this ecosystem are found in Davis (1943) and Loveless (1959).

In the model of Figure (23) marl solution and deposition are depicted in addition to the mechanism of evapotranspiration, and the biological interactions among macrophytes, periphyton, wildlife and man. The major forcing functions shown are: rain, inflow of water, ground water composition, sunlight, wind, dry air, and fossil fuels. The main producers are the aquatic macrophytes and periphyton. The important consumers are microbes and invertebrates, frogs, and other carnivores. Frogging is a major activity in this ecosystem and man is shown harvesting frogs and other game animals. The major biological interactions shown are the production of oxygen and organic matter (detritus) by photosynthesis and the role of these two substances in powering the food chains and the respiratory processes of both plants and animals. Respiration in turn is shown releasing carbon dioxide and minerals and these are depicted recycling as feedbacks into the photosynthetic process. Many of these feedbacks as well as organic export from the system are shown to be operated through the switching and pumping action by water levels in the system. Water levels are shown to be dependent on rainfall and run-off for inputs and to evapotranspiration for losses. Standing water is also shown as an unlimited energy source into a constant gain amplifier powering high evapotranspiration. The process of evapotranspiration is powered by heat (derived from sunlight), dry air (which provides a high saturation deficit) and wind. Wind maintains the diffusion gradient and drives moist air away. Plants contribute to the flow through plant transpiration.

Finally, the chemistry of marl solution and deposition is shown with the energy language, in the lower right side of the model. An important role in this equilibrium is played by periphyton through their actions in the carbon equilibrium and pH and the quality of ground water as a source of calcium. The dynamics of marl formation is now being studied by researchers in the department of Biology at the University of Miami.

Cypress

The diagram in Figure (25) shows the sallent features of the cypress swamp and its interactions with man. Illustrated as the main producers (powered by sunlight) are cypress trees, aquatic plants, other component tree species, and many epiphytes and herbs. These producers provide both local and migratory wildlife with an abundant diversity of foods shown in the model as a storage.

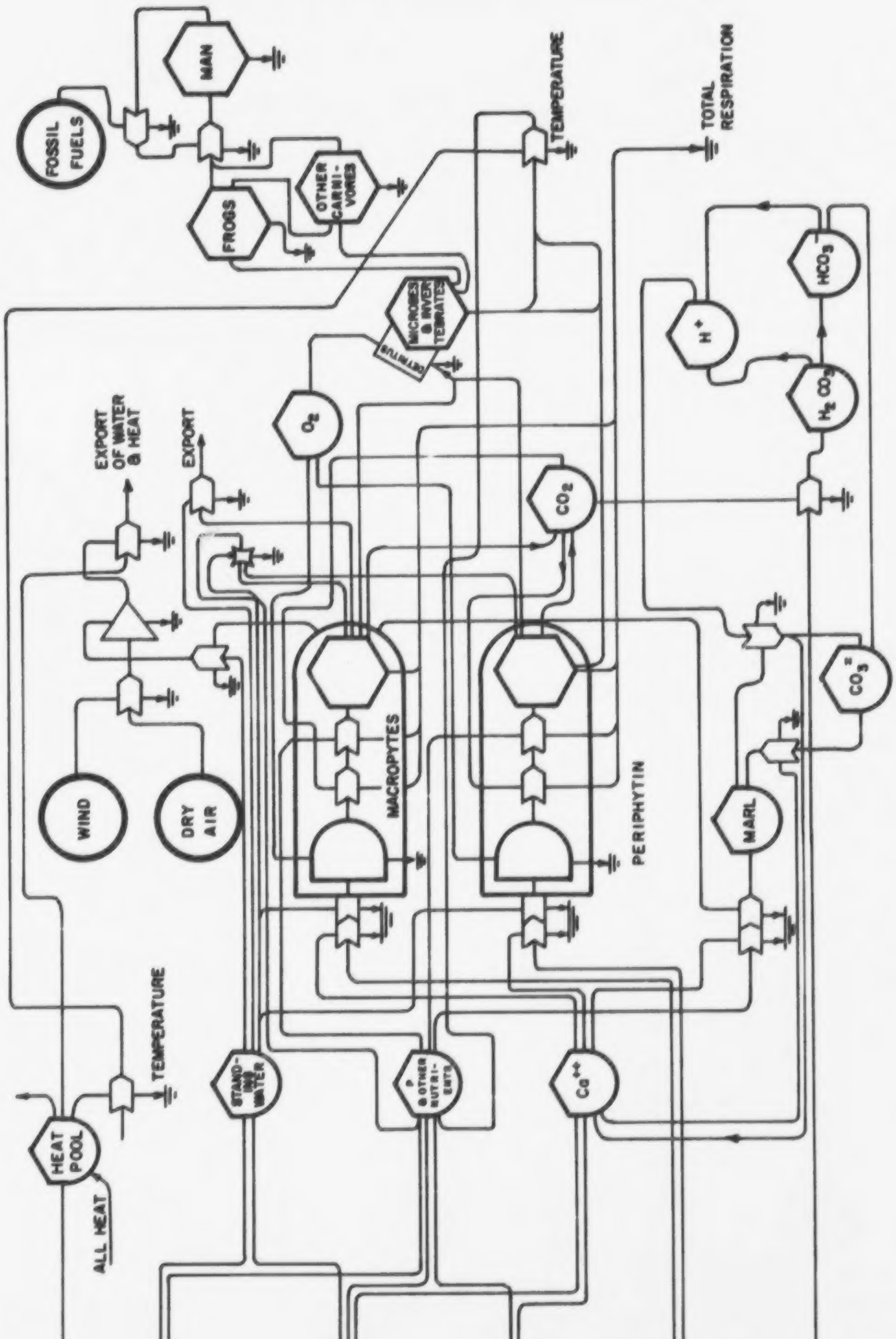

FOSSIL FUELS
MAN
OTHER CARNIVORES
FROGS
TEMPERATURE
TOTAL RESPIRATION
MICROBES & INVERTEBRATES
DETRITUS
EXPORT OF WATER & HEAT
EXPORT
O2
CO2
H+
HCO3
H2CO3
CO3=
WIND
DRY AIR
MACROPYTES
PERIPHYTIN
MARL
TEMPERATURE
HEAT POOL
ALL HEAT
STANDING WATER
P & OTHER NUTRIENTS
Ca++
RAIN
INFLOW WATER
GROUND WATER COMPOSITION
SUN

Figure 23. Wet prairie.

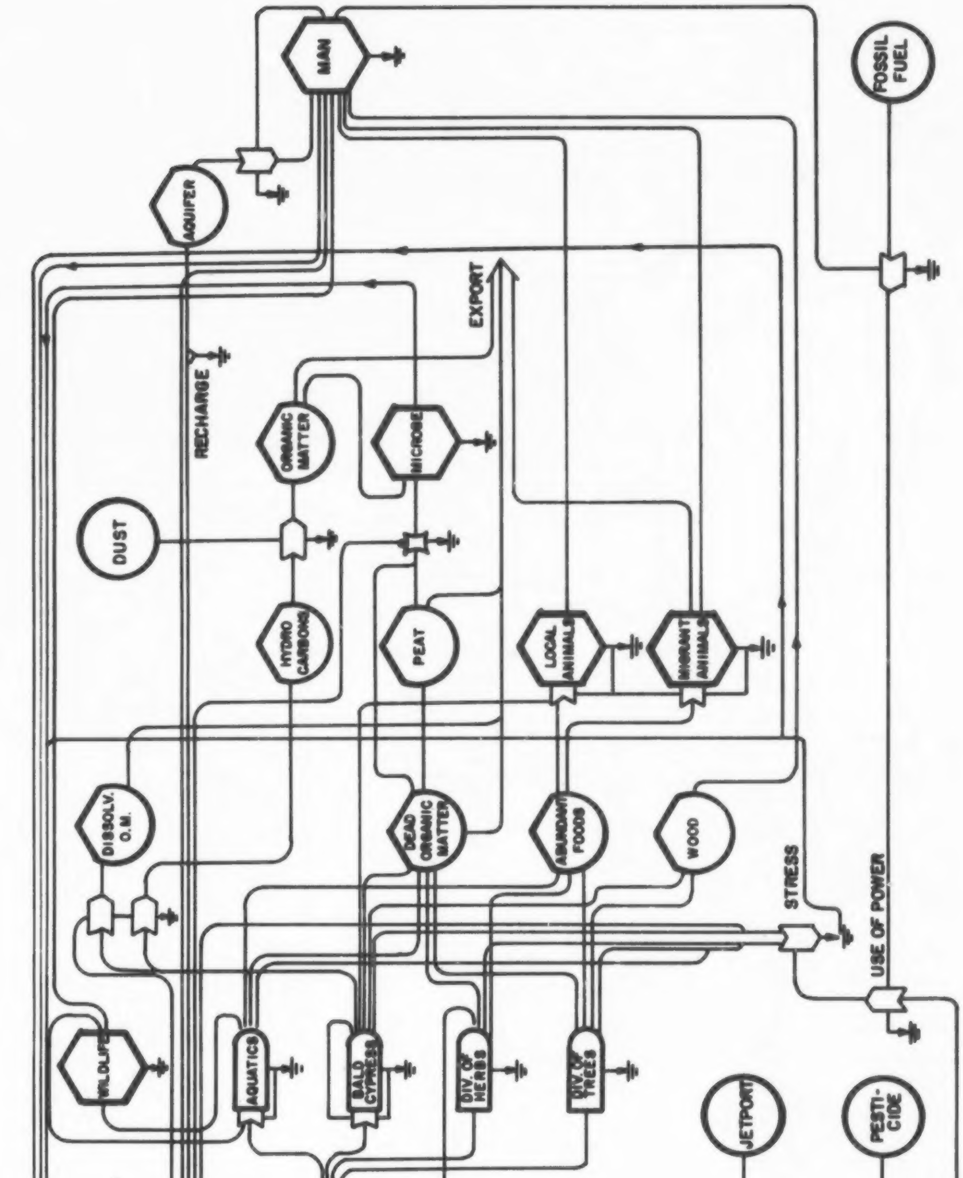

WORK OF WILDLIFE
RAIN
SUN
MINING
FERTILIZER
SILTATION
AGRI.
NUTRIENTS
WATER LEVEL
RUNOFF
FIRE
WASTE
RESIDENTIAL
CATTLE
WILDLIFE
AQUATICS
BALD CYPRESS
DIV. OF HERBS
DIV. OF TREES
JETPORT
PESTICIDE
DISSOLV. O.M.
DEAD ORGANIC MATTER
ABUNDANT FOODS
WOOD
STRESS
USE OF POWER
HYDRO CARBONS
PEAT
LOCAL ANIMALS
MIGRANT ANIMALS
DUST
ORGANIC MATTER
MICROBE
RECHARGE
EXPORT
AQUIFER
MAN
FOSSIL FUEL

Figure 25. Cypress swamp.

These wildlife species are then shown to have specialized roles in the mineral cycles of the system. A feedback entering the nutrient storage symbol illustrates this function. Also contributing to the nutrient pool are the decomposers which do work on the pool of dead organic matter and peat (each shown as a separate storage). Notice that the water level has a switching action on decomposition; when the water is high, oxygen becomes limiting to decomposition and the switch is Off. The cypress trees are the dominant species and have interesting adaptations and interactions with the other components of the system. Shown in the model are the characteristic cypress knees which are presumed to contribute to high productivity by pumping oxygen into the roots (growing in anaerobic conditions) and therefore stimulate mineral and water movement through the trees. In addition, cypress trees are known to produce hydrocarbons and dissolved organic matter (such as tannic acid) which might be important to the system's energy economy (Greenfield, et al., 1970). In the model these substances are shown to interact with water level which serves as a medium for dispersal. In addition, the hydrocarbon films pick up dust from the air and therefore become enriched with organic matter which may serve as a fuel for the decomposers. These interactions are shown in the model. Peat, wildlife components, and the hydrocarbon-dust films are shown as export pathways to other systems. This emphasizes the coupling of the cypress swamps with surrounding ecosystems.

On the left portion of the diagram, the large workgate represents all system interactions that promote and maintain productivity. Shown as performing these functions are; the many specialized activities of wildlife (grazing for example), nutrient availability, water level (which also acts as a selective force on plants), and the many specialized functions of other plant components, such as the role of epiphytes in nutrient removal from rainfall. Rainfall is shown as the only source of water to the basin as has been discussed in many reports.

The interactions of man are many. In terms of benefits from the system, we show his harvest of wood, aquatic and terrestrial wildlife, and water from the aquifer. Notice that man must work to obtain water from the aquifer. This is shown by a workgate on the water flow. On the negative side, man stresses the systems as his intrusions increase. In this model we show stress as dependent on two factors: demand and availability of power, and the many uses shown on the left as energy sources. As the demand for power in the urban system increases; the use of power goes up; and as the use of power increases, the activities of man, shown on the left, also increase. These, for example, are: use of pesticides, jetports, cattle grazing, agriculture, housing, siltation, waste production, fertilizer use, minimg, and fire frequency. All these of course, have an effect on the system by stressing the producers and wildlife.

Pineland

Pinelands, like many other ecosystems, exist in a precarious balance with their environment as illustrated in Figure (26). Any shift in environmental conditions, particularly the frequency of fire, permits hardwoods to invade and replace pine as the dominant species (Alexander and Dickson, 1970).

In order to emphasize the internal biological detail, only solar energy, rain, and such external forces such as lightening, are shown as forcing functions in the systems model. The dominant components of the vegetation are pines (canopy), a diverse understory of palms and hardwood, and a herbaceous layer composed of seedlings and repair (successional) species. The important environmen factors are soil moisture, available nutrients, fire and the substrate.

Fire, in this example, is shown as a consumer of organic matter. Robertson (1953) has described fire frequencies and the effects on the pineland ecosystem in the Evergaldes National Park. Fires occur when moisture is low and an ignition source is operational. This is shown with two switches and the presence of dry fuel (litter). Because of the relatively high frequency of fire, the litter storage is kept low even though it is continually being replenished by programmed leaf fall. The programming (phenology) of the forest events have not been sufficiently documented. Pines are fire adapted species, illustrated in the model as thick bark, specialized phenological patterns (e.g., growth) and the production of combustible needles. Fire is also shown to stress hardwoods causing heavy mortality and preventing their assumption of dominance. In addition, fire releases (shown as a switch) and repair specialist species which are adapted to germination in burned or otherwise with several stressed areas. Some of these species also fix nitrogen and as a group act as a multiplier on the whole system. This is shown as a feedback on the producers. The rapid-growing producers in particular provide food and cover to a diversity of consumers associated with the pineland ecosystem. The consumers are shown to have an important role in the system through their mineral recycling work.

The interaction of soil, water and plants is thought to have a role in determining plant species composition. The first, of course, is the obvious role of water in photosynthesis and transpiration shown by a multiplier. Because of the shallow substrate, root space is limited and thus the unavailability of water and nutrients is dependent upon a relatively small storage. This limitation of critical resources exerts an influence on species densities and survival. These interactions are illustrated in the lower right hand portion of the model.

Also shown in the model are suggested specialized roles for the species comprising the diverse hardwood understory. For example, each species could have an important function in accumulating and storing a specific mineral as has been shown for other forest components elsewhere in the United States. In general the pineland ecosystem like all others present lacks quantitative description of its structure and function in a specialized role of the component species.

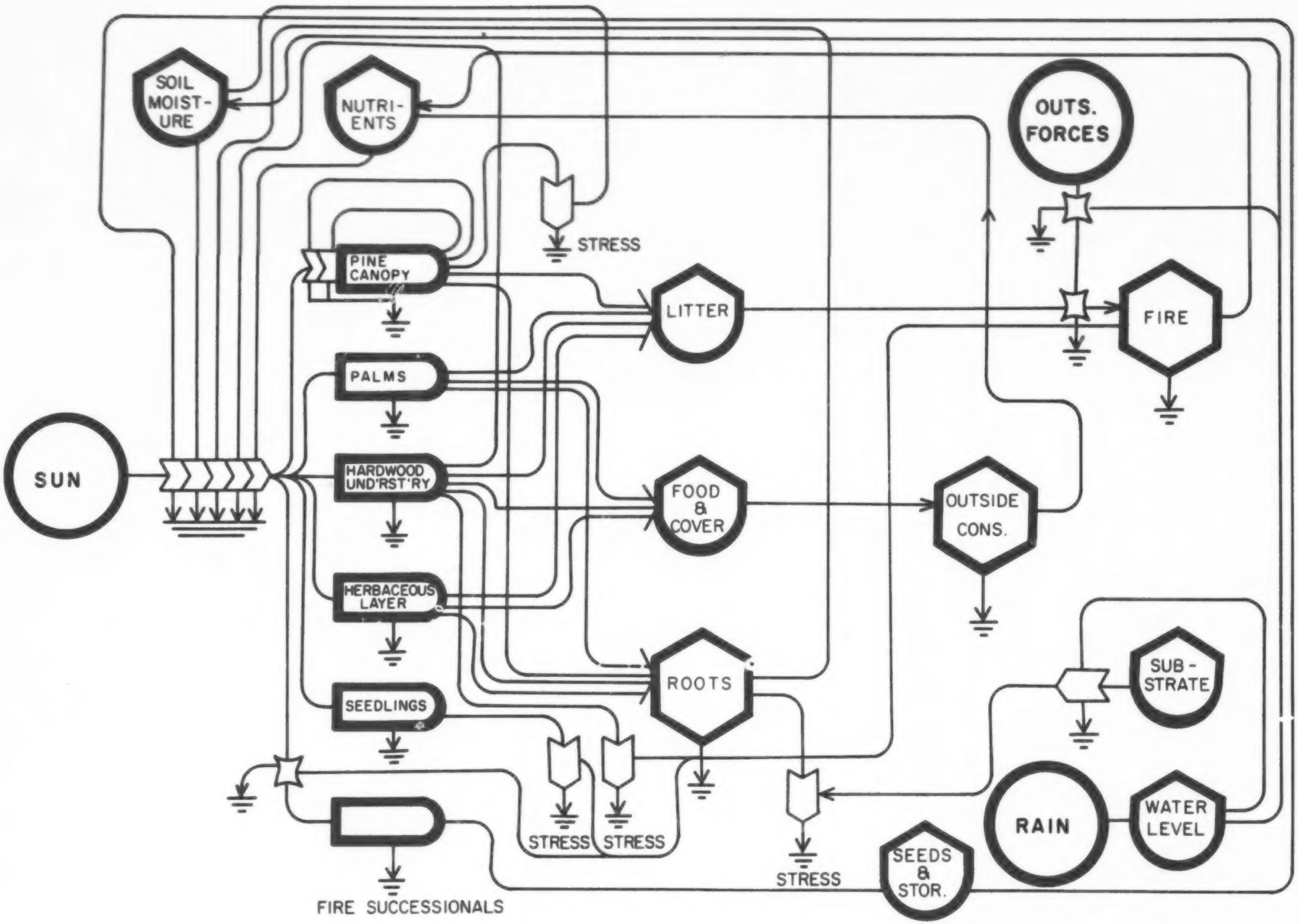

SOIL MOIST-URE
NUTRI-ENTS
OUTS. FORCES
STRESS
PINE CANOPY
LITTER
FIRE
PALMS
SUN
HARDWOOD UND'RST'RY
FOOD & COVER
OUTSIDE CONS.
HERBACEOUS LAYER
ROOTS
SUB-STRATE
SEEDLINGS
STRESS
STRESS
RAIN
WATER LEVEL
STRESS
SEEDS & STOR.
FIRE SUCCESSIONALS

Figure 26. Pinelands.

APPENDIX C - COMPUTATIONS OF SEDIMENTATION RATES FROM TRAP DATA

I. Laboratory methodology

A. Let sample settle for 24 hours

B. Test for Halides (CL^-) on a sample of supernatant

C. Decant off supernatant to near solids level

D. Tare burned and cooled crucible (crucible weight)

E. Add solids and liquid to crucible (use known volume of rinse water)

F. Weigh (wet weight + crucible)

G. Dry at 105° C for 24 hours

H. Weigh (dry weight + crucible)

I. Burn for one hour at 550° C

J. Wet the ash and dry at 105° for 24 hours

K. Weigh (ash weight + crucible)

II. Calculations

L.* Salt concentration = $(1.850)(CL^-\ mg/l) + 30$

M. Total weight salts = (volume salt water dried)(salt concentration)

$$= (F - H - \text{rinse water})\left(\frac{gm}{ml}\right) L$$

N. Organic weight = H - K in 300 ml sample

O. Inorganic weight = K - D - M in 300 ml sample

P. Total organic weight = $N \left(\frac{\text{liters of sample}}{0.333 \text{ liter (sub sample)}}\right) = gm$

Q. Organic deposition rate = P ÷ (elapsed time in days) ÷ (area of sampler) = $gm/m^2/day$

R. Total inorganic weight = $O \left(\frac{\text{liters of sample}}{0.333 \text{ liter (sub sample)}}\right) = gm$

S. Inorganic deposition rate = R ÷ (elapsed time in days) ÷ (area of sampler) = $gm/m^2/day$

* Knudsen formula - S ppt = 1.850 CL ppt + 0.030 in ppt

APPENDIX D - INHABITANTS FOUND IN SEDIMENTATION TRAPS

Fahka Union Bay

Unidentified crab - 1

Skilletfish - 1

Goby - 17

Toadfish - 1

Snapper - 1

Blue crab - 21

Silver perch - 10

Sheepshead - 2

Snapping shrimp - 1

Jewfish - 2

Shrimp - 68

Number of species - 11

Number of individuals - 125

Frequency of occurrence - 50/126

Fahkahatchee Bay

Snail - 1

Goby - 23

Toadfish - 6

Snapper - 2

Blue crab - 11

Sheepshead - 2

Skilletfish - 1

Shrimp - 32

Number of species - 8

Number of individuals - 78

Frequency of occurrence - 52/126

Total

Number of species - 12

Number of inidividuals - 203

Frequency of occurrence - 102/252

APPENDIX E - SAMPLING STATION SITE DESCRIPTIONS AND LOCATIONS

Station	Description and Location
1	Southeast corner of bridge at mile 18.5 on Alligator Alley (S. R. 84). An off-shoot from the Borrow Canal draining southward into the Fahkahatchee Strand. A freshwater station.
2	North side of bridge at mile 19.5 on Alligator Alley (S. R. 84). An off-shoot from the Borron Canal draining southward into the Fahkahatchee Strand. A freshwater station.
3	South side of bridge east of the junction of S. R. 29 and Alligator Alley (S. R. 84) on the Borron River. A freshwater station.
4	South side of bridge in front of Janes Resturant on S. R. 29 on the Barron River. A freshwater station.
5	South side of wooden bridge on Janes Scenic Drive 4.83 kilometers (3 miles) from the fire tower. A freshwater station on the outer edge of Fahkahatchee Strand.
6	25 meters (27.4 yards) north of Fort Myers Tram at a point on the Tram 100 meters (109 yards) from the junction of Fort Myers Tram and Janes Scenic Drive. A freshwater station close to the middle of Fahkahatchee Strand.
7	A culvert on Janes Drive 14.48 kilometers (9 miles) from the fire tower. A freshwater station slightly outside of the Fahkahatchee Strand, but occasionally receives water from the strand.
8	North side of bridge 71 on U. S. 41 (Tamiami Trail). An off-shoot of the Borron Canal draining southward into a salt marsh. It has brackish water and is subject to tidal influence.
9	North side of bridge 64 on U. S. 41 (Tamiami Trail). An off-shoot of the Borron Canal draining southward into a salt marsh. It has brackish water and is subject to tidal influence.
10	North side of weir on Fahka Union Canal close to U. S. 41. A freshwater station.
F-1	Fahkahatchee River at first fork going upstream. An estuarine station.
F-2	Approximate center of Fahkahatchee Bay.

APPENDIX E - SAMPLING STATION SITE DESCRIPTIONS AND LOCATIONS (CONT'D)

Station	Description and Location
F-3	South of Fahkahatchee Bay in the middle of Fahkahatchee pass.
FU-1	Midstream of Fahka Union Canal at the junction of Fahka Union River approximately 2.90 kilometers (1.8 miles) downstream from U. S. 41. An estuarine station.
FU-2	Fahka Union Bay east of Black Marker 35 in mid-channel.
FU-3	Fahka Union Bay east side of Black Marker 9 in the middle of Fahka Union pass.

APPENDIX F - SPECIFIC TEST USED FOR EACH WATER CHEMISTRY ANALYSIS

Temperature: *In situ* using a Beckman Model RS5-3 salinometer.

Conductivity: *In situ* using a Beckman Model RS5-3 salinometer.

pH: Fisher Accumet Model 220 pH meter using a glass electrode in combination with a reference potential (Saturated calomel electrode).

Apparent color: Visual comparison of nonclarified sample with paltinum-cobalt standards.

Turbidity: Hach Model 2100A turbidimeter, which was calibrated with a formazin standard freshly prepared every week.

Dissolved oxygen: The modified Winkler with full-bottle technique. Samples were fixed in the field with 2 ml of manganous sulfate solution and 2 ml alkali azide solution. In the laboratory, samples were acidified and titrated with standardized sodium thiosulfate.

Alkalinity: An unaltered sample was manually titrated to an electrometrically determined end point of pH 4.5.

Chloride: Acidified samples with diphenylcarbazone bromophenol blue indicator and titrated with mercuric nitrate solution.

Sulfate: The sulfate ion was converted to a barium sulfate suspension which was read as turbidity by the Hach Model 2100 A turbidimeter and compared to a curve prepared from standard sulfate solution.

Total and soluble Kjeldahl nitrogen: A portion of the sample was filtered by passing it through a 0.45-μ Millipore filter membrane. The unfiltered portion was analyzed for total Kjeldahl nitrogen, and the filtrate was analyzed for total soluble Kjeldahl nitrogen. The nitrogen was determined using the microglassware-nesslerization procedure.

Total and soluble phosphorus: A portion of the sample was filtered by passing it through a 0.45-μ Millipore filter membrane. The unfiltered protion was analyzed for total phosphorus, and the filtrate was analyzed for total soluble phosphorus. The single reagent method, which is found in the EPA manual, was used for the analyses of both total and soluble phosphorus.

Total and soluble organic carbon: A portion of the sample was filtered by passing it through a 0.45-μ Millipore filter paper. Both filtered and unfiltered portions were preserved with 2 ml concentrated H_2SO_4 per liter and then sent to the Southeast Environmental Research Laboratory in Athens, Georgia, for analysis. The unfiltered portion was analyzed for total organic carbon, and the filtrate was analyzed for soluble organic carbon. Both forms of carbon were analyzed on the Beckman Total Organic Carbon Analyzer according to EPA procedures.

Nitrate-nitrite nitrogen: Samples were preserved with 2 ml concentrated H_2SO_4 per liter and then shipped to the Southeast Environmental Research Laboratory in Athens, Georgia, for analysis by the automated cadmium reduction method.

APPENDIX F - SPECIFIC TEST USED FOR EACH WATER CHEMISTRY ANALYSIS (CONT'D)

Tannin and lignin "like" compounds: For both the freshwater and estuarine samples, the procedure in the Standard Methods for the Examination of Water and Wastewater, 13th Ed. was followed except that for the estuarine samples, a filtering procedure was employed after the addition of the sodium carbonate solution. This was to eliminate the precipitate from metal carbonates. Tannin and lignins and other hydroxylated aromatic compounds are detected by this method.

APPENDIX G - STANDING CROP BIOMASS OF BENTHIC VEGETATION IN FAHKA UNION AND FAHKAHATCHEE BAYS, JANUARY 1972

Plant type and relative density	Percent of total bay area supporting vegetation	Standing crop biomass (kg dry wt)
	Fahkahatchee Bay	
Green filamentous algae		
Trace	31.2	1,393
Medium	6.8	4,503
Heavy	2.2	7,645
Total	40.2	13,541
Red macro-algae		
Trace	39.5	883
Medium	20.9	2,488
Heavy	0.0	0
Total	60.4	3,371
Marine grasses		
Trace	29.4	1,311
Medium	18.1	2,154
Heavy	10.1	6,191
Total	57.6	9,756
	Fahka Union Bay	
Green filamentous algae		
Trace	42.4	4,812
Medium	14.1	2,376
Heavy	10.9	9,661
Total	67.4	16,849
Red macro-algae		
Trace	23.8	102
Medium	3.9	90
Heavy	0.0	0
Total	27.7	192
Marine grasses		
Trace	17.8	153
Medium	0.0	0
Heavy	5.3	623
Total	23.1	776

APPENDIX H - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING SAND-MUD BOTTOM OF FAHKAHATCHEE AND FAHKA UNION BAYS, JULY 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Total standing crop biomass (kg dry wt)
Fahkahatchee Bay (299.6 ha)[b]			
Marine grasses	250.4	23.6 (1.1 - 150.1)	59,094
Red macroalgae	256.3	2.5 (0.0 - 47.4)	6,407
Green filamentous algae	256.3	0.7 (0.0 - 0.8)	1,794
No vegetation	43.3		
Total			67,295
Fahka Union Bay (20.4 ha)[b]			
Marine grasses	20.4	16.1 (0.0 - 31.2)	3,288
Red macroalgae	0.0	0.0	0
Green filamentous algae	0.0	0.0	0
No vegetation	0.0	0.0	0
Total			3,288

[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate.

APPENDIX I - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING MUD-SAND BOTTOM AREA IN FAHKAHATCHEE AND FAHKA UNION BAYS, JULY 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Total standing crop biomass (kg dry wt)
Fahkahatchee Bay (386.8 ha)[b]			
Marine grasses	224.2	48.8 (0.4 - 296.0)	109,410
Red macroalgae	339.0	1.9 (0.0 - 30.0)	6,441
Green filamentous algae	114.8	0.2 (0.0 - 2.2)	23
No vegetation	47.8		
Total			115,874
Fahka Union Bay (143.1 ha)[b]			
Marine grasses	60.1	7.4 (1.3 - 11.9)	445
Red macroalgae	121.2	1.8 (0.0 - 8.6)	2,229
Green filamentous algae	121.2	7.6 (0.0 - 37.8)	9,238
No vegetation	21.9		
Total			11,912

[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate

APPENDIX J - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING SHELL BOTTOM IN FAHKAHATCHEE AND FAHKA UNION BAYS, JULY 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Standing crop biomass (kg dry wt)
Fahkahatchee Bay (56.8 ha)[b]			
Marine grasses	11.2	12.7 (3.7 - 17.1)	1,426
Red macroalgae	34.0	1.6 (0.0 - 3.1)	554
Green filamentous algae	0.0	0.0	0
No vegetation	22.8		
Total			1,980
Fahka Union Bay (25.8 ha)[b]			
Marine grasses	0.0		
Red macroalgae	0.0		
Green filamentous algae	0.0		
No vegetation	25.8		

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[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate

APPENDIX K - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING MUD-SAND BOTTOM IN FAHKAHATCHEE AND FAHKA UNION BAYS, SEPTEMBER 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Standing crop biomass (kg dry wt)
Fahkahatchee Bay (386.8 ha)[b]			
Marine grasses	317.4	43.1 (0.0 - 250.1)	136,799
Red macroalgae	317.4	2.0 (0.0 - 28.1)	6,396
Green filamentous algae	5.4	10.5[c]	567
No vegetation	64.0	0.0	0
Total			143,762
Fahka Union Bay (143.1 ha)[b]			
Marine grasses	57.0	5.0 (3.2 - 13.3)	2,850
Red macroalgae	49.4	21.9 (0.0 - 132.5)	108,341
Green filamentous algae	40.6	38.1 (10.3 - 96.1)	15,472
No vegetation	36.7	0.0	0
Total			126,663

[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate

[c] Only one observation

APPENDIX L - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING SAND-MUD BOTTOM IN FAHKAHATHCEE AND FAHKA UNION BAYS, SPETEMBER 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Standing crop biomass (kg dry wt)
Fahkahatchee Bay (299.6 ha)[b]			
Marine grasses	277.5	39.1 (0.0 - 152.5)	108,502
Red macroalgae	277.5	13.9 (0.0 - 207.1)	38,572
Green filamentous algae	0.0	0.0	0
No vegetation	22.1	0.0	0
Total			147,074
Fahka Union Bay (20.4 ha)[b]			
Marine grasses	20.4	4.6[c]	938
Red macroalgae	0.0	0.0	0
Green filamentous algae	0.0	0.0	0
No vegetation			
Total			938

[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate

[c] Only one observation

APPENDIX M - STANDING CROP BIOMASS OF BENTHIC VEGETATION INHABITING SHELL BOTTOM IN FAHKAHATCHEE AND FAHKA UNION BAYS, SEPTEMBER 1972

Plant types	Area (ha)	Mean conc.[a] (gm dry wt /m^2)	Standing crop biomass (kg dry wt)
Fahkahatchee Bay (56.8 ha)[b]			
Marine grasses	25.6	1.5 (0.3 - 2.9)	384
Red macroalgae	44.3	2.6 (0.0 - 10.4)	1,152
Green filamentous algae	0.0	0.0	0
No vegetation	12.5	0.0	0
Total			1,536
Fahka Union Bay (25.8 ha)[b]			
Marine grasses	0.0	0.0	0
Red macroalgae	9.5	0.8[c]	81
Green filamentous algae	0.0	0.0	0
No vegetation	16.3	0.0	0
Total			81

[a] Mean concentration subtended by range in concentrations

[b] Total area of bay represented by substrate

[c] Only one observation

APPENDIX N - SUMMARY OF MEAN LIGHT EXTINCTION COEFFICIENT WITH RESPECT TO DATE, TIME OF DAY, AND WATER DEPTH, FAHKA UNION BAY WITH MUD-SAND BOTTOM, 1972-73

			Mean light extinction coefficient (K) and standard error of mean		
Date	Time of day	Mean depth (cm)*	Mean K	$S\bar{x}$	Sample size
Feb. 16, 1972	p.m.	64.9	0.0262	0.0014	9
Feb. 16	p.m.	68.1	0.0242	0.0053	3
Feb. 19	a.m.	32.1	0.0496	0.0021	3
Mar. 24	p.m.	101.4	0.0179	0.0004	11
April 6	p.m.	87.8	0.0265	0.0026	10
April 25	a.m.	88.1	0.0215	0.0026	10
Oct. 26	a.m.	75.6	0.0188	0.0017	5
Oct. 27	a.m.	61.0	0.0226	0.0015	4
Nov. 1	a.m.	85.0	0.0157	0.0009	2
Nov. 4	a.m.	ND	0.0213	0.0006	2
Nov. 4	a.m.	33.1	0.0143	0.0010	3
Nov. 5	a.m.	113.4	0.0274	0.0030	2
Dec. 7	a.m.	58.5	0.0318	0.0025	10
Feb. 14, 1973	a.m.	92.8	0.0141	0.0010	10
Mean K			0.0237		

* mean depth during time interval of light extinction measurements

APPENDIX O - SUMMARY OF MEAN LIGHT EXTINCTION COEFFICIENT WITH RESPECT TO DATE, TIME OF DAY, AND WATER DEPTH, FAHKAHATCHEE BAY WITH SAND-MUD BOTTOM, 1972-73

Date	Time of day	Mean depth (cm)*	Mean light extinction coefficient (K) and standard error of mean		
			Mean K	$S_{\bar{x}}$	Sample size
Feb. 18, 1972	p.m.	114.3	0.0359	0.0034	2
Mar. 7	a.m.	74.4	0.0255	0.0001	3
Mar. 7	p.m.	91.7	0.0294	0.0006	6
Mar. 16	a.m.	106.7	0.0171		1
Mar. 16	p.m.	161.3	0.0149	0.0001	2
Mar. 24	p.m.	112.8	0.0131	0.0007	6
April 25	a.m.	122.2	0.0158	0.0014	6
Oct. 31	p.m.	112.9	0.0198	0.0020	6
Nov. 2	p.m.	71.9	0.0378	0.0043	2
Nov. 4	p.m.	164.3	0.0107	0.0018	4
Dec. 7	p.m.	63.0	0.0310	0.0037	6
Feb. 14, 1973	p.m.	117.1	0.0129	0.0021	6
Mean K			0.0220		

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* mean depth during time interval of light extinction measurements

APPENDIX P - SUMMARY OF MEAN LIGHT EXTINCTION COEFFICIENT WITH RESPECT TO DATE, TIME OF DAY, AND WATER DEPTH, FAHKAHATCHEE BAY WITH MUD-SAND BOTTOM, 1972-73

Date	Time of day	Mean depth (cm)*	Mean light extinction coefficient (K) and standard error of mean		
			Mean K	$S_{\bar{x}}$	Sample size
Feb. 18, 1972	a.m.	53.1	0.0323	0.0032	6
Feb. 18	p.m.	213.4	0.0216		1
May 7	p.m.	120.4	0.0319	0.0002	4
May 8	a.m.	86.9	0.0198	0.0005	3
May 8	p.m.	76.2	0.0208	0.0003	3
May 10	p.m.	102.9	0.0244	0.0005	2
May 14	p.m.	142.0	0.0160	0.0020	3
May 16	p.m.	146.3	0.0208		1
May 24	a.m.	121.6	0.0138	0.0010	9
May 24	p.m.	77.8	0.0293	0.0026	10
April 6	p.m.	96.3	0.0232	0.0018	10
April 25	a.m.	116.1	0.0169	0.0016	10
Oct. 29	p.m.	78.5	0.0194	0.0013	6
Oct. 30	p.m.	80.8	0.0208	0.0012	2
Nov. 1	p.m.	86.7	0.0201	0.0062	2
Nov. 4	a.m.	117.0	0.0338	0.0007	4
Nov. 4	p.m.	121.0	0.0250	0.0015	5
Dec. 7	p.m.	67.5	0.0325	0.0023	10
Feb. 14, 1973	a.m.	115.1	0.0150	0.0016	10
Mean K			0.0230		

* mean depth during time interval of light extinction measurements

APPENDIX Q - BENTHIC GROSS PRIMARY PRODUCTIVITY (GPP) IN FAHKA UNION AND FAHKAHATCHEE BAYS EMPLOYING LIGHT AND DARK CHAMBERS, SPRING AND FALL 1972

		Chamber conditions						
			Initial					
System	Date	Type	Temp. °C	D.O. (mg/1)	Time interval for rate (hrs.)	Rate of D.O. metabolism 10^{-2} mg/1/min	GPP 10^{-2} mg/1/min	Vis. light transmission at bottom 10^{-2} ly/min
FU-MS[a]	Feb. 15	Light	22.5	7.2	1330 - 1409	-1.29578	0.5516	6.252
"	"	Dark	22.4	"	1332 - 1405	-1.84738		
"	"	Light	23.5	7.3	1459 - 1541	-1.22880	0.1666	1.427
"	"	Dark	22.0	"	1501 - 1543	-1.39539		
"	"	Light	23.6	7.4	1625 - 1702	-1.69990	0.1683	0.357
"	"	Dark	23.8	"	1632 - 1704	-1.86818		
"	Feb. 16	Light	23.5	5.8	1110 - 1226	-0.37392	0.5431	5.392
"	"	Dark	22.1	"	1148 - 1250	-0.91699		
F-MS[b]	Feb. 18	Light	23.0	4.2	0932 - 1035	+0.09447	0.8940	2.605
"	"	Dark	22.0	"	0943 - 1032	-0.79950		
"	"	Light	21.9	4.7	1117 - 1132	+2.53807	4.5730	7.679
"	"	Dark	21.9	"	1122 - 1157	-2.03494		
"	"	Light	23.0	5.4	1306 - 1327	+2.84615	4.2433	7.223
"	"	Dark	24.0	"	1245 - 1337	-1.39719		
"	Mar. 8	Light	ND	6.8	1103 - 1127	+1.56667	2.3911	3.0307
"	"	Dark	23.0	"	1144 - 1238	-0.82447		
"	"	Light	25.3	7.2	1545 - 1615	+0.10952	2.5485	4.489
"	"	Dark	25.5	"	1544 - 1626	-2.43900		
"	Mar. 10	Light	24.0	7.4	1438 - 1448	+0.51266	1.8440	4.362
"	"	Dark	22.5	"	1430 - 1445	-1.33136		
F-SM[c]	Feb. 17	Light	23.8	5.8	1358 - 1448	-0.41467	0.4794	0.727
"	"	Dark	22.5	"	1406 - 1502	-0.89405		
"	Feb. 18	Light	23.0	7.8	1453 - 1521	-1.77350	0.5819	1.363
"	"	Dark	24.0	7.4	1442 - 1521	-2.35539		
"	Mar. 7	Light	24.0	"	1130 - 1206	+1.04167	1.5717	4.000
"	"	Dark	24.0	"	1204 - 1257	-0.53005		
"	"	Light	24.0	"	1332 - 1430	-0.05430	1.1357	4.000
"	"	Dark	24.0	"	1353 - 1335	-1.19000		
"	Mar. 24	Light	23.2	7.2	1526 - 1648	-0.59630	0.1037	0.316
"	"	Dark	23.0	"	1558 - 1638	-0.70000		

APPENDIX Q - BENTHIC GROSS PRIMARY PRODUCTIVITY (GPP) IN FAHKA UNION AND FAHKAHATCHEE BAYS EMPLOYING LIGHT AND DARK CHAMBERS, SPRING AND FALL 1972 CONT'D

System	Date	Chamber conditions			Time interval for rate (hrs.)	Rate of D.O. metabolism 10^{-2} mg/1/ min	GPP 10^{-2} mg/1/ min	Vis. light transmission at bottom 10^{-2} ly/min
			Initial					
		Type	Temp. °C	D.O. (mg/1)				
FU-MS[a]	Oct. 26	Light	27.3	5.0	0815 - 0900	-0.86666	1.0333	3.118
"	"	Dark	27.8	7.5	0905 - 0940	-1.90000		
"	"	Light	28.0	"	0915 - 0945	-1.50000	0.4000	4.879
"	"	Dark	27.8	"	0905 - 0940	-1.90000		
"	Oct. 27	Light	28.8	5.1	0957 - 1046	+0.11820	0.6971	4.109
"	"	Dark	28.8	"	1010 - 1055	-0.57894		
"	"	Light	29.0	5.8	1100 - 1128	+0.27714	3.4350	5.751
"	"	Dark	30.0	"	1245 - 1315	-3.15789		
"	Nov. 1	Light	27.2	5.9	1018 - 1039	+6.00396	8.3873	11.430
"	"	Dark	27.6	"	1034 - 1058	-2.38333		
"	"	Light	27.1	5.7	1213 - 1231	+2.83333	4.7389	9.862
"	"	Dark	28.0	"	1251 - 1315	-1.90559		
"	Nov. 4	Light	27.0	5.5	0848 - 0857	+2.66660	5.3036	10.521
"	"	Dark	27.0	6.8	1753 - 1810	-2.63698		
"	"	Light	27.0	5.5	0917 - 0925	+10.10000	12.7370	22.669
"	"	Dark	27.0	6.8	1753 - 1810	-2.63698		
"	"	Light	27.2	5.5	0945 - 0950	+10.00000	12.6370	20.346
"	"	Dark	27.0	6.8	1753 - 1810	-2.63698		
"	Nov. 5	Light	27.8	5.1	0745 - 0818	-1.25174	0.5705	2.700
"	"	Dark	28.0	"	0746 - 0813	-1.82222		
F-MS[b]	Oct. 29	Light	28.5	4.6	0915 - 1015	+3.23140	6.1647	5.463
"	"	Dark	29.4	"	0945 - 1020	-2.93333		
"	"	Light	29.9	5.5	1015 - 1115	+0.30000	3.2333	3.207
"	"	Dark	29.4	5.9	1230 - 1300	-2.93330		
"	"	Light	29.9	5.7	1145 - 1209	+2.44220	5.1090	5.329
"	"	Dark	30.2	5.9	1230 - 1300	-2.66667		
"	"	Light	30.7	6.1	1300 - 1330	-0.28111	2.3856	2.441
"	"	Dark	30.2	5.9	1230 - 1300	-2.66667		

APPENDIX Q - BENTHIC GROSS PRIMARY PRODUCTIVITY (GPP) IN FAHKA UNION AND FAHKAHATCHEE BAYS EMPLOYING LIGHT AND DARK CHAMBERS, SPRING AND FALL 1972 CONT'D

		Chamber conditions						
			Initial					
System	Date	Type	Temp. °C	D.O. (mg/1)	Time interval for rate (hrs.)	Rate of D.O. metabolism 10^{-2} mg/1/min	GPP 10^{-2} mg/1/min	Vis. light transmission at bottom 10^{-2} ly/min
F-MS[b]	Nov. 2	Light	27.8	6.0	1515 - 1530	-1.25714	3.2786	2.230
"	"	Dark	27.6	"	1510 - 1528	-4.53571		
"	"	Light	28.0	5.6	1613 - 1631	-2.04285	2.6016	2.228
"	"	Dark	27.8	"	1609 - 1633	-4.64444		
"	"	Light	27.5	5.2	1720 - 1738	-2.85714	2.2095	1.496
"	"	Dark	27.8	"	1725 - 1737	-5.06666		
F-SM[c]	Oct. 31	Light	28.4	5.8	1128 - 1221	-0.24471	0.8101	8.333
"	"	Dark	28.4	"	1239 - 1330	-1.05478		
"	"	Light	28.7	6.0	1227 - 1257	-0.47619	0.5786	7.729
"	"	Dark	28.4	"	1239 - 1330	-1.05478		
"	"	Light	29.0	6.1	1306 - 1345	-0.83023	0.2246	5.830
"	"	Dark	28.4	"	1239 - 1330	-1.05478		
"	"	Light	29.0	7.3	1546 - 1607	-2.02333	0.0704	1.8731
"	"	Dark	29.0	"	1512 - 1600	-2.09375		
F-SM[c]	Nov. 4	Light	28.2	5.8	1500 - 1545	-1.16507	0.4005	4.844
"	"	Dark	28.4	"	1445 - 1545	-1.56557		
"	"	Light	28.2	6.8	1603 - 1651	-1.43677	0.3378	3.310
"	"	Dark	28.5	"	1600 - 1650	-1.77456		
"	Nov. 5	Clear	28.2	5.1	0910 - 0949	+1.17998	2.1800	12.444
"	"	Dark	27.4	"	0914 - 0950	-1.00000		

[a] Fahka Union Bay - Mud-sand bottom

[b] Fahkahatchee Bay - Mud-sand bottom

[c] Fahkahatchee Bay - Sand-mud bottom

APPENDIX R - METHODS, METABOLIC STUDIES

A general exposition of the methodology employed in this study for the determination of plant community carbon and water dynamics has been presented earlier in Chapter XII. In this appendix we detail some modifications of standard methods developed to deal with local environmental conditions, and describe the particular methodologies and equipment configurations utilized. We attempted to incorporate most of the precautionary measures advocated by Brown (1968), with appropriate modifications to adapt the procedures he received for physiological investigations, to a field ecological study.

Our primary objective was to minimize the disturbance of the ecosystem involved in our attempts to measure the dynamics of metabolic behavior. This required efforts to maintain environmental parameters of significance to plant community metabolism at near-ambient levels, especially CO_2 concentration, light levels, and temperature. In addition, mobile field deployment of substantial quantities of complex equipment required the development of a general standardized procedure, designed to minimize potential sources of error in the measurement system, although these were of unequal magnitude in the several communities that were studied.

In general, the method consisted of isolating a segment of the plant community in a rigid, clear polyacetate chamber. The chambers were run as open systems, and the gradient in CO_2 and water vapor concentration induced between the inlet and outlet ports were analyzed in terms of grams of carbon and grams of water fixed or released per unit time. The effect of the materials (0.5 cm polyacetate) used for chamber construction on the ambient solar energy regime was examined with an Isco Spectroradiometer, kindly lent for this purpose by the University of Florida. All materials acted as neutral filters, and suppressed incoming visible light radiation (400 to 700 nm) by approximately 3 percent. The chambers employed for studies of wet prairie, salt marsh, and ground cover vegetation were of two types. The first was a cylindrical chamber 1 meter in diameter and 1 meter high. Occasionally, two of these chambers were stacked for tall-grass communities, to give a single chamber 1 meter in diameter and 2 meters high. The second type was an inverted "U" shaped chamber that was 3 feet high, 2 feet wide, and 3 feet long. These chambers were often coupled end-to-end to create one 6-foot chamber, especially for short grass prairies. All of these chambers were constructed of welded steel rod (one-fourth inch in diameter) to minimize shading in the chambers due to rigid structural elements. For woody plants too large for these chambers, plastic sheaths were used to enclose portions of the plant, and the dynamic behavior of the organs studied was extrapolated to the entire stand from independent studies of the structural properites of the stand. These sheaths ballooned to a rigid form when the air supply was introduced to them; and under these conditions, measured about 1.2 meter in length by 0.6 meter in diameter.

The air flow to any given chamber was in almost all cases constant during any particular diel run. Flow rates were commensurate with observed daytime wind speeds and of sufficient magnitude to maintain five to six turnovers per minute in the chambers. These turnover rates kept the temperature gradient across the chamber within 4 to 5°C of ambient temperatures under the worst conditions encountered (early afternoons of clear, hot summer days on dry shortgrass prairies) and usually limited noon temperature gradients to about 2°C.

Carbon dioxide concentration gradients generally were limited to 5 to 10 ppm, thus eliminating artificial CO_2 starvation as a factor supressing observed net photosynthesis. The air flow was introduced at the proximal end of the chamber, near ground level, via a plastic container cut to provide divergence of the incoming air stream at the inlet port. Outlet parts were located at the distal, top side of the chamber and provided with clear plastic "chimneys" to minimize turbulent air exchange through the port. Air flow rates were monitored daily, with a hot-wire anemometer placed at a third-point in the inlet duct to measure average flow. Cross-sectional area of the duct multiplied by flow rate then gave air mass delivery rate. Generally, four chambers (often of varying type) were deployed during any given diel run; and each was monitored for metabolic activity over a 15-minute cycle every hour.

Calculation of carbon dynamics from the CO_2 gradient across the chamber is given by (derived from Brown, 1968):

$$\text{g C/hr} = 0.14625\ (\Delta\text{ppm})\ (F)\ /T \qquad \text{(Eq. 1)}$$

where (Δppm) is the value of the CO_2 gradient, F is the air flow rate in m^3/hr, and T is the temperature measured at the same point in the inlet duct as was flow in ^{o}K.

The frequent occurrence of nighttime (ambient) air mass stagnation (due to temperature inversions) posed special problems to this analysis. Under these conditions, ambient CO_2 concentrations frequently exceeded 600 ppm and occasionally exceeded 800 ppm during short time intervals. Given that noon concentrations were usually 290 to 300 ppm, the simultaneous maintenance of high instrument sensitivity (for chamber gradients) and an extremely large range (for monitoring ambient concentration) offers certain technical difficulties in that the objectives are basically incompatible. In addition, nighttime small-scale atmospheric eddies introduced transient temporal CO_2 gradients as large as 50 ppm/min at the inlet ports, which effectively quenched the 5-ppm signal of interest derived from plant metabolism. The latter problem was resolved by deriving the source air stream from an elevation of some 10 meters above ground level in the prairie communities and about 4 meters above the canopy in wooded stands. In addition, the source air was pumped to a 13.6-m^3 buffer (tent) and then distributed to the chambers by individual, electrically driven pumps located inside the buffer (Figure R-1).

Equal-length cables, each consisting of three lengths of 7.9-mm I.D. tygon tubing, were used to conduct the air streams to the infared gas analyzer (IRGA, Beckman model 215B). In order to maintain acceptable precision and range in the analysis, a tripartite gas-flow sequence was used over each 15-minute measurement cycle.

1. A standard bottled gas (300 ppm CO_2 in H_2) was introduced to the reference side of the IRGA, and comparison with the ambient air stream established the absolute level of CO_2 in the air. This part of the analysis was performed using "Range 1", the least sensitive range of the instrument. (IRGA calibration for this sector of the analysis was accomplished by least squares regression (parabolic model) of IRGA response to a series of bottle gases of differing CO_2 concentration. Calibration procedures are given in more detail later in this appendix.)

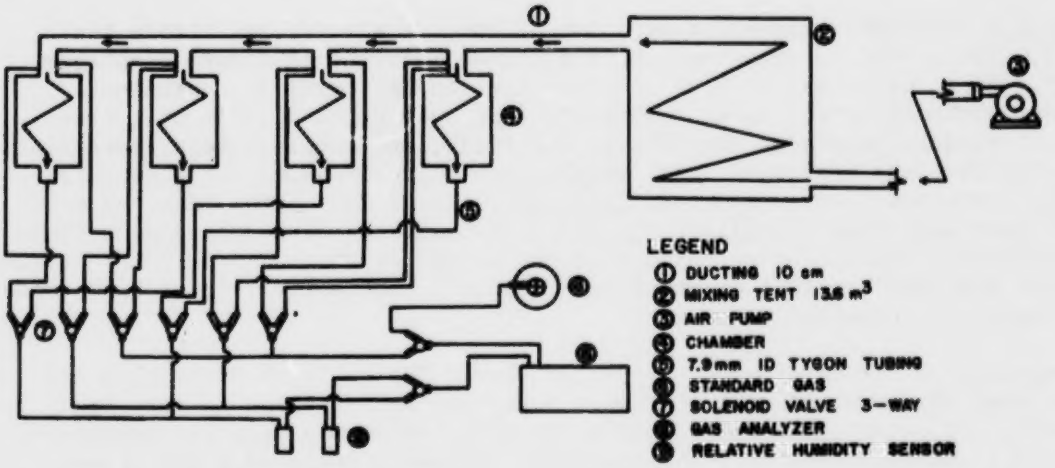


Figure R-1. Simplified schematic of gas flow control.

2. A selectroswitch, programmable timer then switched the input gases (Figure R-1) to flow ambient air to the reference side of the analyzer and chamber exhaust air to the "read" side of the IRGA. At the same time, the timer switched the IRGA from range 1 to range 3, the latter with a very small total range (about 60 ppm total span at 300 ppm baseline).

3. In the final step, ambient air was channeled to both sides of the IRGA to give a hard value for the "no difference" point in the readings. Range 3 calibration of the IRGA essentially involved parameterization (LSR) of instrument sensitivity as a function of the CO_2 content in the reference cell.

This procedure provided knowledge of the absolute concentration of CO_2 in the ambient air stream and the instrument deflection produced by passage of the gas through the plant chamber (step 2) versus the "no difference" deflection (if any--this step compensated for zero drift of the IRGA). With calibrated values for the sensitivity of the instrument, it was possible to calculate the absolute level of CO_2 in the chamber exhaust stream and, thus, the gradient across the chamber. This gradient corresponds to the factor (Δppm) in Eq. 1.

Success of this analytical scheme hinged on several key features of the IRGA. First, the instrument is indifferent to which of the cells is regarded as the "reference" and which the "read" cell, except that the meter gives off-scale (negative) readings for one of the alternatives. The use of an external recorder (Honeywell Electronik 194) permitted a setting of instrument "zero" at mid-range on the recorder. In this way, daytime carbon fixation and night-time carbon release could be monitored with equal facility. Secondly, range 3 (R3) amounts to nothing more than a porportional expansion of a given segment of the range 1 (R1) response curve. Treatment of a small length of this curve (under the range of calibrations here utilized) as a straight-line segment introduced an error of no more than 0.2 to 0.3 ppm and permitted efficient parametrization of the IRGA sensitivity as a function of ambient CO_2 concentration.

A manifold and a large vacuum pump was used to maintain constant purging of the sampling lines, thus minimizing water condensation in the lines. One-way check valves prevented cross-contamination of chamber air streams within the manifold. Pumps used to transport the air stream into the IRGA were diaphragm pumps of a type that does not leak air into the sample stream or contaminate the stream with oil, etc. Range 1 zero and span were checked daily by introduction of standard gases to the IRGA in the field, and complete reparameterization of IRGA response was performed approximately monthly. The same air flow rates (and gauge pressures) were used for field analysis and for calibration and were of sufficient magnitude to fully purge the instrument chambers during each phase of the analytical cycle. Flow rates were maintained at stable (1.5 l/min) levels by pumping gas into the IRGA chambers and frequently monitoring output flow rates with permanently installed rotameters.

Compensation for interference by water vapor, due to light absorption at infrared wavelengths within the analyzer, poses special problems to this kind of analysis. In-line dessicant chambers are often used to predry the sample streams prior to injection into the analyzer. However, there does not appear to be any fully satisfactory drying agent available. Brown (1968) judged silica gel to be inadequate for this application, and we found Drierite ($CaSO_4$) to be extremely reactive in terms of intrinsic CO_2 uptake and release properties under the conditions of this analysis. This was despite extensive trials involving varying column sizes, preconditioning schedules, etc. Ultimately, we adapted a procedure of relying upon the internal temperature control of the IRGA as a means of preventing condensation in the analyzer chambers and did not predry the air streams.

Calibration data provided by the manufacturer with the instrument indicate an interference by water vapor of an apparent concentration change of 10.5 ppm at 3.5 mol percent in range 1. This water vapor content is equivalent to that of a fully saturated air stream at $87^{\circ}F$ (B. R. Strain, personal communication) run against a fully dried air stream. The error introduced to the R1 readings of this study was therefore about 2 percent. In R3, the 10.5 shift represents about 20 percent of full scale. However, the change in relative humidity between the chamber input and output streams rarely exceeded 10 percent and was more usually on the order of 4 to 7 percent. In general then, the mode of analysis used in this study limited the range 3 error introduced by neglect of water vapor interference to a point maximum of about 10 percent of the measured CO_2 value under worst case conditions, with a more usual error of about 2 percent of the measured value for both range 1 and range 3. Furthermore, the error was not fully systematic; for under many conditions, small quantities of water vapor condensation occurred in the chambers and were reflected in the readings.

Water export from the plant community was measured by routing the sample stream from chamber inlet and outlet ports through relative humidity transducers (Hygrodynamics 15-7012 W). Each sensor received a constant air supply from either the inlet or outlet port during the entire 15-minute measurement cycle. Output of one sensor was recorded (analog trace) for the first 8 minutes of the cycle, at which point the output was electircally switched to the other sensor. Values of the difference were read from charts at the switching point to give fully synpotic and fully stabilized pairs of RH values for comparison of inlet and outlet air streams. Each sensor had a paired thermocouple probe to establish the true temperature at the sensor. Saturated water vapor content at that temperature was derived from logarithmic interpolation of the Smithsonian Tables (Handbook of Chemistry ahd Physics, CRC Publishing Co.). Throughout the analysis (both for CO_2 and for H_2O), atmospheric pressure was taken as a constant one bar. Water export rate during any 15 minute measurement cycle can then be expressed as

$$g\ H_2P/hr = \left[(RH)_i\ S_{T_i} \ - \ (RH)_o\ S_{T_o}\right] F \qquad \text{(Eq. 2)}$$

where RH is relative humidity, S is saturated water content (g H_2O/m^3) at the relevant temperature T, i and o refer to inlet and outlet chamber port airstreams respectively, and F is the air flow delivery rate in m^3/hr.

In the case of ground chambers, carbon and water export rates were corrected by ground areas occupied by the chambers to give g $C/m^2 \cdot hr$ and g $H_2O/m^2 \cdot hr$, respectively. In the latter case, conversion to mm of water export is directly from the relationship

$$1\ kg\ H_2O/m^2.hr = \ mm/hr\ .$$

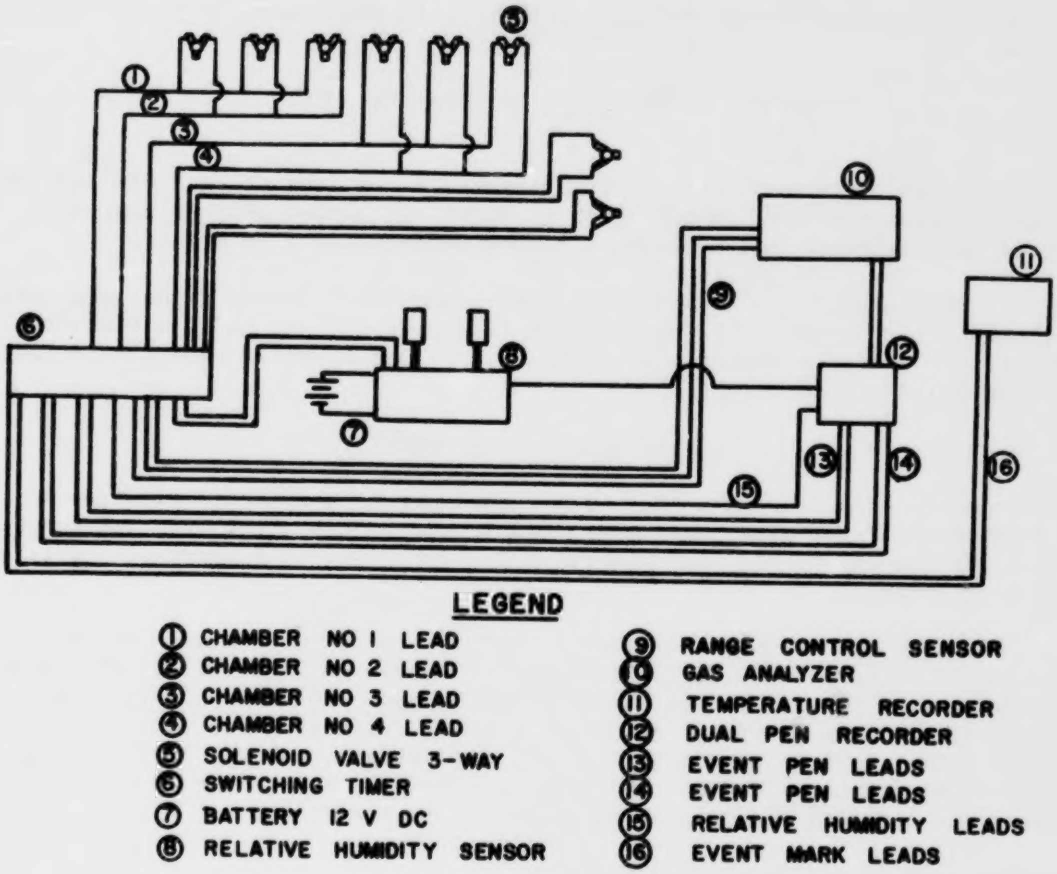
All temperature records were made with copper constontan (Honeywell Type T) thermocouples or polyvinyl over polyvinyl insulated extension wire (16 gauge, #S-12876C) coupled to thermocouple reference junctions of a Honeywell multipoint thermocouple recorder (Model 112).

A simplified schematic of the electrical control mechanisms run by the programmable ("Selectroswitch") microtimer is given in Figure R-2. The timer was a series of 14 gauged SPDT switches programmed by plastic blocks inserted on a revolving drum (1 rph). Solenoid valves for gas flow control, RH sensor outputs, etc., were switched, in the patterns described above, by this time. In addition, positive identification of each step of the full hour cycle was provided by recorder event marks programmed into the timer.

IRGA Calibration and Sample Calculations

Range 1 parameterization of the IRGA response was conducted by least squares regression of a parabolic model on observed recorder response levels. The IRGA performed in a differential mode, based on departures from a 300 ppm zero point (i.e. 300 ppm CO_2 in N_2 on both "reference" and "read" sides of the analyzer). The analyzer gain was set to give a meter deflection of 25 units for the 100 ppm shift in concentration of 300 ppm (reference) vs 400 ppm ("read" or "sample" cell). A sample calibration run is given in Table R-1, with the resultant calibration curve in Figure R-3. The slight deviations of the observed points from the calibration curve are primarily due to variation in the CO_2 content of the bottled gases. Composition of these gases as delivered is rated at ± 3 ppm. Also, caution must be used when bottle pressures get low, as concentration shifts occur due to the differing molecular weights of the CO_2 and carrier N_2.

Calibration of range 3 was accomplished by parameterization of IRGA sensitivity (expressed as ppm/scale division) against a series of standard gases introduced to the reference cell. A closed system (Figure R-4) of known total volume was injected serially with specific volumes of pure CO_2. To eliminate cumulative errors, each injection was considered in terms of the concentration change thereby induced, and paired with the corresponding meter or recorder change. This resulted in a paired data set of (Δppm/Δscale divisions), i.e. sensitivity as ppm/scale division, vs the CO_2 concentration in the reference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② CHAMBER NO 2 LEAD
③ CHAMBER NO 3 LEAD
④ CHAMBER NO 4 LEAD
⑤ SOLENOID VALVE 3-WAY
⑥ SWITCHING TIMER
⑦ BATTERY 12 V DC
⑧ RELATIVE HUMIDITY SENSOR
⑨ RANGE CONTROL SENSOR
⑩ GAS ANALYZER
⑪ TEMPERATURE RECORDER
⑫ DUAL PEN RECORDER
⑬ EVENT PEN LEADS
⑭ EVENT PEN LEADS
⑮ RELATIVE HUMIDITY LEADS
⑯ EVENT MARK LEADS

Figure R-2. Simplified schematic of electrical controls.

Table R-1. Sample calibration of CO_2 analyzer range 1 using standard gases and 300 ppm reference.

Sample gas ppm	Meter reading	Recorder reading
200	<0	11.6
300	0	50
350	15.0	65.0
400	25	75

Sample gas ppm = $ax^2 + bx + c$
x = recorder reading
$a^* = 2.3237 \times 10^{-2}$
$b^* = 1.1041 \times 10^{0}$
$c^* = 1.8433 \times 10^{2}$

* Values generated by least squares regression.

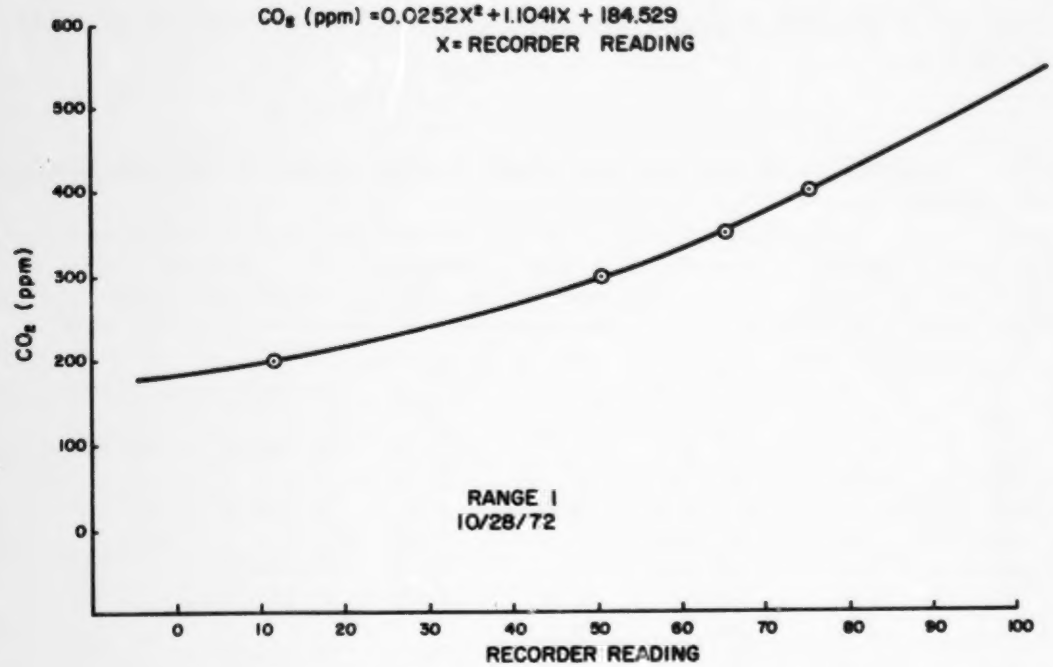
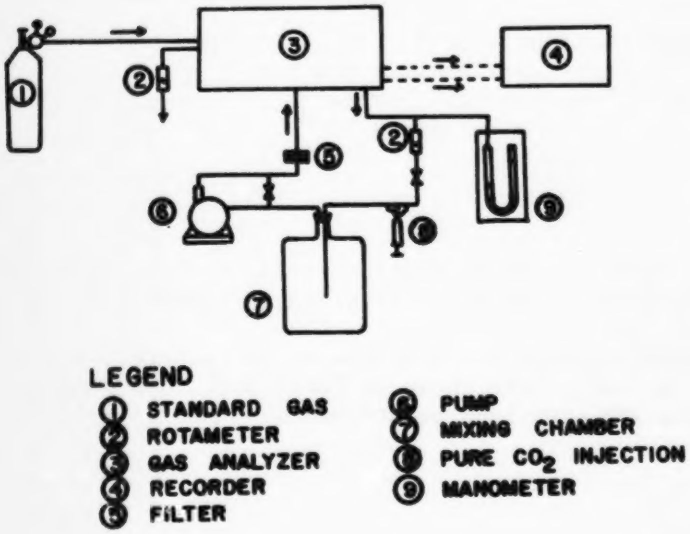


Figure R-3. Sample Range 1 calibration curve.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LEGEND
① STANDARD GAS
② ROTAMETER
③ GAS ANALYZER
④ RECORDER
⑤ FILTER
⑥ PUMP
⑦ MIXING CHAMBER
⑧ PURE CO_2 INJECTION
⑨ MANOMETER

Figure R-4. Schematic of closed-system range 3 IRGA calibration.

cell. Table R-2 presents a simplified version of one calibration run utilizing this procedure.

Table R-2. Calibration of CO_2 analyzer range 3 using closed system and standard gas references.

Reference gas (ppm)	Sample gas (cc)	Sample gas (ppm)	Meter reading	Recorder reading	ppm per scale division
0	0	0	<0	44.2	
0	0.4	20.139	57.5	117.5	20.139/73.3 = 0.275
100	2.0	100.695	9.0	59.0	
100	2.4	120.834	71.4	121.4	20.139/62.4 = 0.323
200	4.0	201.390	<0	34.8	
200	4.4	221.528	31.9	81.9	20.139/47.1 = 0.428
300	6.0	302.084	<0	14.0	
300	6.4	322.223	1.7	51.7	20.139/37.7 = 0.534
300	6.8	342.362	37.9	87.9	20.139/36.2 = 0.556
350	6.8	342.362	<0	1.7	
350	7.2	362.501	<0	35.5	20.139/33.8 = 0.596
350	7.6	382.640	19.3	69.3	20.139/33.8 = 0.596
350	8.0	402.779	51.7	101.7	20.139/32.4 = 0.622
400	8.0	402.779	-2.0	48.0	
400	8.4	422.918	29.7	79.7	20.139/31.7 = 0.635
400	8.8	443.057	61.3	111.3	20.139/31.6 = 0.637

ppm per scale division = ae^{bx}

x = ambient ppm

$a = 2.727 \times 10^{-1}$

$b = 2.225 \times 10^{-3}$

This data set was fitted to an exponential model by LSR. The calibration curve resulting from the data of Table R-2 is given in Figure R-5.

Sample calculations incorporating the above calibration data, hypothetical recorder outputs, and Eq. 1 are shown in Table R-3. All computations were performed using the LSR equations programmed on a Monroe Model 1760 desk-top calculator.

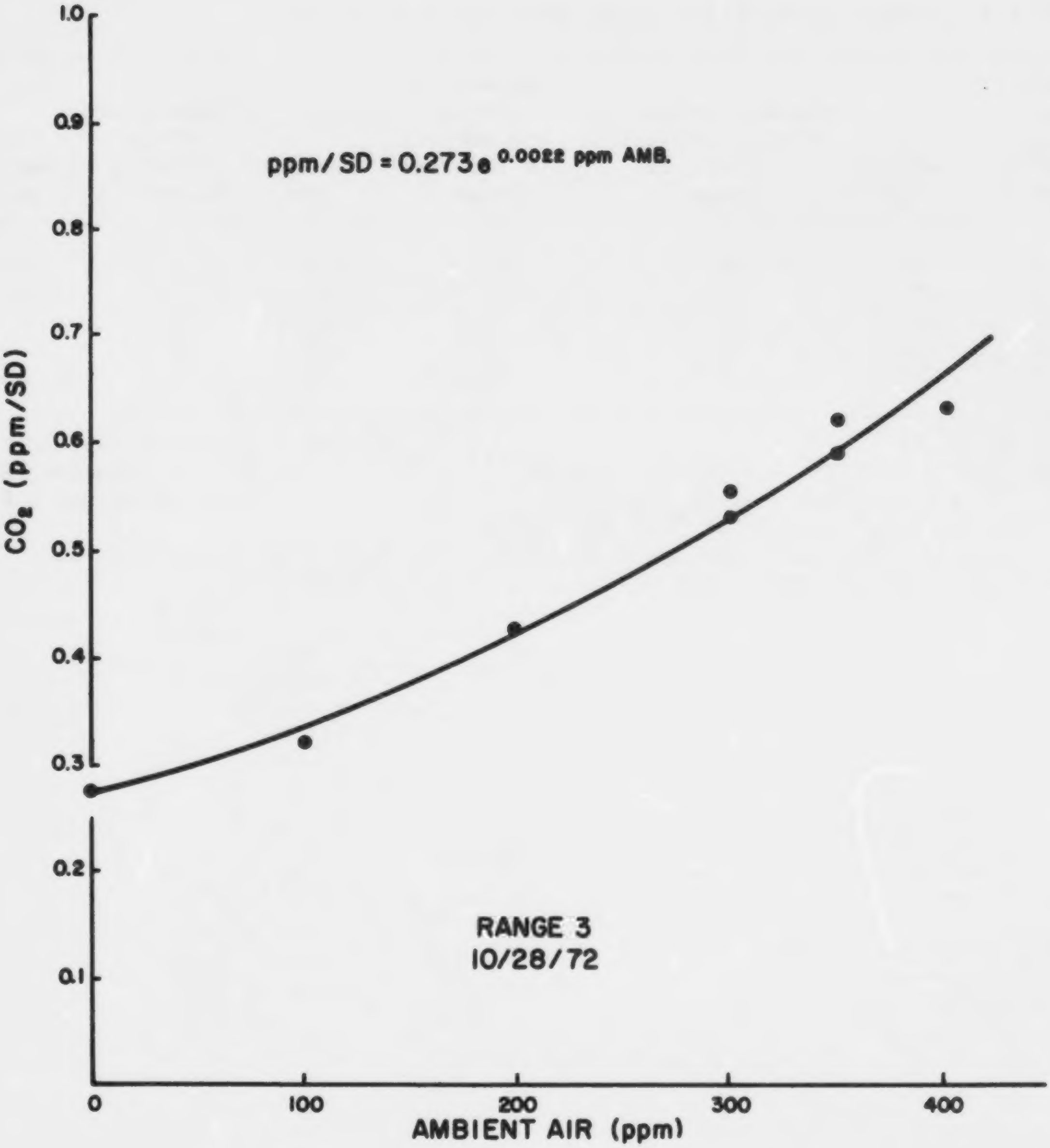

Figure R-5. Sample range 3 calibration curve.

Table R-3. Sample calculations of CO_2 exchange in chambers.

Ambient to sample, 300 ppm to reference (Range 1)	Ambient ppm	Chamber exhaust to sample, ambient to reference (Range 3)	Ambient to sample and ambient to reference (Range 3)	Exhaust ppm	Temperature of air entering chamber °C	Carbon metabolism gm C/hr[a]
50.0	297.6	48.5	50.2	296.7	0	-0.0481
49.8	296.9	40.2	49.9	291.8	43.3	-0.2368
50.2	298.3	52.3	50.2	299.4	48.9	0.0505
50.1	298.0	50.8	49.6	298.6	37.8	0.0299
50.0	297.6	39.8	50.0	292.2	47.8	-0.2459

Flow = 100 m^3/hr

Ambient ppm[b] = $0.0232X^2 + 1.1041X + 184.329$

X = recorder reading (range 1)

ppm/scale division[b] = $0.273\, e^{0.0022}$ (ppm amb.)

Δppm = (Δscale divisions) (ppm/scale division)

Exhaust ppm = ambient ppm + Δppm

[a] gm C/hr = $\left[(0.14625)(\Delta ppm)/{}^{\circ}K\right] \cdot F$ (Eq. 1) Negative values = P
Positive values = R

[b] Taken from calibration data Tables R-1 and R-2.

APPENDIX S - PHYSICAL DIMENSIONS AND RELATED BIOMASS (DRY WT) OF TEN SPECIES INCLUDING SEEDLINGS.

Genus species	DBH (cm)	Height (cm)	Wood mass (gm)	Green leaves (gm)
Taxodium distichum var. nutans (pond cypress)	14.3	820	38,291.5	607.3
	24.5	1,156	154,939.5	1,685.2
	1.2	224	292.1	9.3
	18.8	1,150	94,059.9	1,291.4
	10.6	565	11,301.8	780.7
	22.9	1,486	60,964.0	2,382.7
Sabal palmetto (cabbage palm)	24.9	600	90,503.0	3,700.0
	23.5	877	115,2[illegible].0	4,267.0
	19.0	1,110	125,89[illegible]0	8,827.0
	19.2	602	50,892.0	4,521.0
	28.3	500	72,653.0	6,487.0
	23.1	411.8	46,933.0	4,451.0
	20.1	363	24,169.0	2,454.0
	24.2	1,030	128,296.0	8,935.0
	23.5	925	114,272.0	6,031.0
Acer rubrum* (red maple)	27.0	1,171	328,838.3	1,085.2
	15.6	1,236	70,494.0	1,320.1
	21.7	1,222.5	153,857.1	977.1
	30.3	1,483	366,538.9	5,389.0
	15.2	1,161	64,981.4	1,170.9
	13.2	947	44,166.8	625.1
	7.6	1,025	15,274.6	1,363.6
	8.5	954	15,264.0	2,013.4
	5.3	755	1,643.5	822.4
	9.1	1,008	15,128.4	293.6
	7.9	831	10,143.0	271.2
Fraxinus caroliniana* (pop ash)	10.3	1,010	34,069.4	72.5
	5.4	760	6,502.0	14.3
	3.3	470	1,928.4	none
	4.6	640	4,623.6	8.5
	3.4	570	1,939.4	none
	14.2	1,300	69,821.9	none
	15.2	1,400	85,911.2	1,587.9
	18.4	1,350	120,893.2	280.9
Salix caroliniana* (water willow)	9.8	813	15,717.3	131.5
	7.9	742	14,963.3	490.4
	11.2	798	21,468.2	166.1
	12.1	848	31,605.3	135.9
	8.3	782	8,115.3	142.3
	9.7	1,095	18,702.1	657.2
	15.6	894	28,253.4	462.8
	18.8	1,053	125,167.1	455.4
	17.7	950	97,687.2	1,310.4
	18.4	1,153	128,649.5	694.8

APPENDIX S - PHYSICAL DIMENSIONS AND RELATED BIOMASS (DRY WT) OF TEN SPECIES INCLUDING SEEDLINGS. CONT'D.

Genus species	DBH (cm)	Height (cm)	Wood mass (gm)	Green leaves (gm)
Annona glabra (pond apple)	15.6	715	25,007.2	459.2
	6.5	780	7,455.0	90.6
	12.5	810	29,596.2	715.4
	19.5	1,000	75,589.4	1,615.7
	14.2	950	50,770.7	1,103.3
	15.3	840	38,417.8	1,004.5
	7.8	970	8,845.7	360.8
	7.2	840	10,432.4	276.1
	Diameter (cm) 20 cm from ground			
Myrica cerifera (wax myrtle)	5.1	260	2,412.2	333.3
	5.2	260	2,895.6	403.7
	4.4	260	1,233.8	179.6
	2.0	190	364.8	33.3
	1.8	160	220.8	42.7
	4.2	350	2,204.2	106.3
	5.9	400	5,236.4	607.3
	6.5	400	5,759.2	759.5
	8.1	400	12,361.8	1,784.4
	1.8	270	219.2	21.6
	4.0	300	1,113.1	120.8
	4.6	250	1,385.0	314.5
	6.6	410	4,092.8	557.7
Baccharis halimifolia (sea myrtle)	1.22	160	98.5	22.7
	0.71	143	22.6	8.7
	1.63	230	204.3	66.0
	0.91	100	22.8	8.8
	0.66	92	11.2	6.0
	0.53	60	4.1	2.2
Magnolia virginiana (sweet bay)	2.38	260	264.8	69.5
	1.05	132	32.6	8.3
	0.63	44	4.0	0.3
	0.32	40	1.8	0.5
	0.49	38	2.2	0.6
Persea borbonia (red bay)	3.70	332	955.8	187.6
	1.29	198	99.5	35.4
	1.52	177	101.5	56.2
	1.51	230	105.5	25.6
	2.58	283	379.4	73.1
	0.57	90	9.6	5.8
	0.62	80	7.9	5.0
	0.33	59	2.1	1.4
	4.25	560	2,818.8	700.5

APPENDIX S - PHYSICAL DIMENSIONS AND RELATED BIOMASS (DRY WT) OF TEN SPECIES INCLUDING SEEDLINGS. CONT'D.

Genus species	Diameter (cm) 20 cm from ground	Height (cm)	Wood mass (gm)	Green leaves (gm)
Taxodium distichum* var. nutans (pond cypress)	2.65 1.80	219 169	126.8 58.6	none none

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* Acer rubrum, Fraxinus caroliniana, Salix caroliniana and Taxodium distichum are deciduous trees, some individuals were taken during or after leaffall.

APPENDIX T - REGRESSION EQUATIONS FOR WOODY BIOMASS BASED ON THE MODEL $y = ax^b$, WHERE y IS TOTAL ABOVE GROUND WOODY BIOMASS IN GRAMS DRY WEIGHT (CONSTANT WEIGHT AT 105° C). THE INDEPENDENT VARIABLE IS $x = \sqrt{D \cdot H}$, WHERE D is DBH IN CENTIMETERS AND H IS TOTAL TREE HEIGHT (CM). SAMPLE SIZE AND CORRELATION COEFFICIENT ARE GIVEN FOR EACH SPECIES INVESTIGATED.

Species	b	a	r	n
Acer rubrum (red maple)	4.3145	4.7382×10^{-5}	0.9852	11
Annona glabra (pond apple)	3.7139	8.7872×10^{-4}	0.9653	8
*Baccharis halimifolia** (sea myrtle)	3.2742	1.3818×10^{-2}	0.9952	6
Fraxinus caroliniana (pop ash)	3.0645	2.1181×10^{-2}	0.9978	8
*Magnolia virginiana** (sweet bay)	2.6315	5.2914×10^{-2}	0.9985	5
*Myrica cerifera** (wax myrtle)	3.1955	1.983×10^{-2}	0.9665	13
*Persea borbonia** (red bay)	2.9426	2.6116×10^{-2}	0.9983	9
Sabal palmetto (cabbage palm)	2.6560	2.1394×10^{-1}	0.9770	9
Taxodium distichum (cypress)	2.4953	2.725×10^{-1}	0.9834	6
*Taxodium distichum** (cypress seedlings)	2.3895	6.328×10^{-2}	1.0000	2

* Diameter taken 20 cm from ground. All others are calculated using DHB diameter at 137 cm.

APPENDIX U - REGRESSION EQUATIONS FOR LEAF BIOMASS BASED ON THE MODEL $y = ax^b$, WHERE y IS TOTAL LEAF BIOMASS IN GRAMS DRY WEIGHT (CONSTANT WEIGHT AT 105° C). THE INDEPENDENT VARIABLE IS $x = \sqrt{D \cdot H}$, WHERE D IS DBH IN CENTIMETERS AND H IS TOTAL TREE HEIGHT (CM). SAMPLE SIZE AND CORRELATION COEFFICIENT ARE GIVEN FOR EACH SPECIES INVESTIGATED.

Species	b	a	r	n
Acer rubrum (red maple)	1.2208	3.0284	0.5432*	11
Annona glabra (pond apple)	3.9190	7.7717×10^{-6}	0.9476	8
Baccharis halimifolia (sea myrtle)	2.6775	2.1218×10^{-2}	0.9948	6
Fraxinus caroliniana (pop ash)	4.2056	3.8224×10^{-7}	0.9346	5†
Magnolia virginiana (sweet bay)	2.7722	8.2460×10^{-3}	0.9666	5
Persea borbonia (red bay)	2.8700	4.5687×10^{-2}	0.9825	9
Sabal palmetto (cabbage palm)	1.5383	3.1299	0.7709	9

* Some *Acer rubrum* were undergoing leaffall.

† Only 5 of the *Fraxinus caroliniana* trees had leaves. At the time of harvest 3 were leafless.

APPENDIX V - REGRESSION EQUATIONS FOR SABAL USING TOTAL HEIGHT.

	b	a	r	n
($Y = ax^b$, Y = wood mass, x = height (m))				
	6.843	1.2687	0.9087	9
($Y = ax + b$, Y = leaf mass (kg), x = height (m))				
	1.0979	0.6199		9

APPENDIX W - DECOMPOSITION OF LITTER CONFINED TO FINE MESH BAGS PLACED ON FOREST FLOOR AND SUBJECTED TO INUNDATION DURING THE HYDROPERIOD, CENTRAL FAHKAHATCHEE STRAND, 1972.

No. of days material subject to decomp.	Vegetative component	Dry wt. (gm)	Ash free wt. (gm)	Organic nitrogen (gm)
0	Leaf	23.6	21.89	0.2596
	Wood	11.6	10.99	0.0821
	Fine	1.2	1.10	0.0229
	Total	36.4	33.98	0.3646
61	Leaf	21.9	19.57	0.3307
	Wood	8.1	7.90	0.0278
	Fine	0.36		0.0061
	Total	30.36	———	0.3646
121	Leaf	14.3	12.90	0.2475
	Wood	9.3	9.15	0.0294
	Fine	0.73		
	Total	24.33	———	———
182	Leaf	15.2	13.34	0.2622
	Wood	8.8	8.60	0.0387
	Fine	-		
	Total	24.0	21.94	0.3009
243	Leaf	16.15	14.06	0.3487
	Wood	8.8	8.59	0.0271
	Fine			
	Total	24.95	22.65	0.3758
311	Leaf	12.5	11.11	0.2310
	Wood	8.3	8.07	0.0262
	Fine	1.1		0.0246
	Total	21.9	———	0.2818
366	Leaf	12.5	10.63	0.2875
	Wood	8.3	8.08	0.0299
	Fine			
	Total	20.8	18.71	0.3174

APPENDIX X - DECOMPOSITION OF LITTER CONFINED TO COARSE MESH BAGS PLACED ON FOREST FLOOR AND SUBJECTED TO INUNDATION DURING HYDROPERIOD, CENTRAL FAHKAHATCHEE STRAND, 1972.

No. of days material subject to decomp.	Vegetative component	Dry wt. (gm)	Ash free wt. (gm)	Organic nitrogen (gm)
0	Leaf	23.6	21.89	0.2596
	Wood	11.6	10.99	0.0821
	Fine	1.2	1.10	0.0013
	Total	36.4	33.98	0.3430
61	Leaf	17.5	15.62	0.2899
	Wood	9.9	9.51	0.0941
	Fine	0.60		0.0093
	Total	28.00	—	0.3933
121	Leaf	13.9	12.63	0.2449
	Wood	9.5	9.36	0.0390
	Fine	0.59		0.0116
	Total	23.99	—	0.2955
182	Leaf	11.7	10.37	0.2064
	Wood	8.3	7.26	0.0365
	Fine	0.59	0.50	
	Total	20.59	18.13	—
243	Leaf	10.9	9.46	0.2457
	Wood	8.2	8.00	0.0476
	Fine			
	Total	19.10	17.46	0.2933
311	Leaf	7.1	6.27	0.1372
	Wood	7.6	7.42	0.0300
	Fine			
	Total	14.7	13.69	0.1672
366	Leaf	11.0	9.44	0.2629
	Wood	6.85	6.63	0.0379
	Fine			
	Total	17.85	16.07	0.3008

APPENDIX Y - DECOMPOSITION OF LITTER CONFINED TO FINE MESH BAGS PLACED ON DEBRIS PILES AND NOT SUBJECTED TO INUNDATION DURING HYDROPERIOD, CENTRAL FAHKAHATCHEE STRAND, 1972.

No. of days material subject to decomp.	Vegetative component	Dry wt. (gm)	Ash free wt. (gm)	Organic nitrogen (gm)
0	Leaf	20.5	18.80	0.2255
	Wood	3.6	3.41	0.0255
	Fine	1.4	1.31	0.0267
	Total	25.5	23.52	0.2777
64	Leaf	16.9	15.20	0.2073
	Wood	3.1	3.02	0.0174
	Fine	1.22		0.0204
	Total	21.22	—	0.2451
120	Leaf	17.4	15.59	0.2339
	Wood	2.9	2.80	0.0155
	Fine	-		
	Total	20.3	18.39	0.2494
193	Leaf	12.45	10.93	0.1869
	Wood	2.00	1.89	0.0151
	Fine	2.10	1.88	0.0341
	Total	16.55	14.70	0.2361
305	Leaf	13.3		
	Wood	2.1		
	Fine	-		
	Total	15.4	13.78	0.2341
366	Leaf	10.6		
	Wood	1.4		
	Fine	2.8		
	Total	14.8		

APPENDIX Z - DECOMPOSITION OF LITTER CONFINED TO COARSE MESH BAGS PLACED ON DEBRIS PILES AND NOT SUBJECTED TO INUNDATION DURING HYDROPERIOD, CENTRAL FAHKAHATCHEE STRAND, 1972.

No. of days material subject to decomp.	Vegetative component	Dry wt. (gm)	Ash free wt. (gm)	Organic nitrogen (gm)
0	Leaf	20.5	19.01	0.2255
	Wood	3.6	3.41	0.0255
	Fine	1.4	1.28	0.0267
	Total	25.5	23.70	0.2777
64	Leaf	16.4	14.64	0.1630
	Wood	3.4	3.22	0.0228
	Fine	0.74		0.0087
	Total	20.54		0.1945
120	Leaf	17.5	15.87	0.2107
	Wood	2.98	2.84	0.0235
	Fine	-	-	-
	Total	20.48	18.71	0.2342
193	Leaf	16.0	14.26	0.2110
	Wood	2.57	2.49	0.0231
	Fine	0.65	0.58	0.0106
	Total	19.22	17.33	0.2447
305	Leaf	14.7		
	Wood	2.68		
	Fine	-		
	Total	17.38	15.37	0.2294
366	Leaf	12.7		
	Wood	2.3		
	Fine	1.2		
	Total	16.2		

APPENDIX AA - TREES AND SHRUBS OF THE CYPRESS STRAND.

Key to Table

Abundance

very rare - less than 1 in 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

large tree - over 10 meters
tree - 5 to 10 meters
small tree - 3 to 5 meters
large shrub - 2 to 3 meters
shrub - 1 to 2 meters
small shrub - less than 1 meter

Substratum

Organic soil } strand
Sandy organic soils } edge

Sandy organic, sandy } strand
and rocky soils } interior

Genus species	Growth habit	Abundance	Substrate
Roystonea elata (Royal palm)	large tree	very rare to rare	organic to sandy organic soil
Sabal palmetto (Cabbage palm)	small tree to tree	rare to infrequent	organic, rocky, and sandy soil
Myrica cerifera (wax myrtle)	shrub to small tree	abundant to very abundant	only on sandy organic, sandy and rocky soil
Taxodium distichum (Bald·cypress)	small to large tree	abundant to very abundant	organic, sandy organic, rocky and sandy soil
Salix caroliniana (Willow)	shrub to large tree	infrequent to abundant	organic soil
Ficus aurea (Strangler fig)	shrub to tree	rare to infrequent	organic, rocky and sandy soil, debris and other plants
Magnolia virginica (Sweetbay)	shrub to tree	very rare to rare	organic, sandy organic, rocky or sandy soil
Annona glabra (Pond apple)	small tree to tree	infrequent to abundant	organic soil
Persea barbonid (Red bay)	shrub to small tree	infrequent to abundant	organic, rocky or sandy soil
Itea virginica (Virginia willow)	shrub to large shrub	very rare to rare	organic soil

APPENDIX AA - TREES AND SHRUBS OF THE CYPRESS STRAND. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Quercus nigra (Water oak)	large tree	very rare to rare	organic, sandy organic soil
Ximenia americana (Hog plum)	shrub to small tree	rare to infrequent	organic, rocky or sandy soil debris
Chrysobalanus icaco (Coco plum)	shrub to small tree	rare to infrequent	organic, rocky or sandy soil debris
Ilex cassine (Dahoon holly)	shrub to large tree	very rare to rare	organic, rocky or sandy soil
Acer rubrum (Red maple)	tree to large tree	abundant	organic to sandy organic soil
Cornus foemina (Dogwood)	small tree	very rare to rare	organic soil
Myrsine quianensis	small to large shrub	infrequent to abundant	organic, rocky and sandy soil debris
Ardisia escallonioides	small to large shrub	rare to infrequent	organic soil and debris
Fraxinus caroliniana (Ash)	large shrub to tree	rare to infrequent	organic soil
Cephalanthus occidentalis (Button bush)	shrub to small tree	very rare to rare	organic or sandy organic soil
Hamelia patens (Fire bush)	small shrub to shrub	very rare	sandy organic soil
Psychotria unudata (Coffee bush)	small shrub to shrub	infrequent to abundant	organic, sandy organic soil and debris
Psychotria salzneri (Coffee bush)	small shrub to shrub	infrequent to abundant	organic, sandy organic soil and debris

APPENDIX BB - VINES OF THE CYPRESS STRAND.

Key to Table

Abundance

very rare - less than 1 in 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 100

Growth habit

very small - less than 2 mm diameter
small - 2 to 5 mm diameter
medium - 5 to 10 mm diameter
large - over 10 mm diameter

liana - vines reaching the top of the strand canopy
vine - vines not usually reaching the top of the strand canopy

Genus species	Growth habit	Abundance	Substrate
Smilax laurifolia (Green brier)	medium to large liana	rare to abundant	organic, sandy organic, rocky and sandy soil
Smilax bona-nox (Green brier)	medium liana	rare to abundant	organic sandy, organic rocky and sandy soil
Passiflora suberosa (Passion flower)	very small herbaceous vine	very rare	sandy organic, sandy and rocky soil
Passiflora pallens (Passion flower)	medium to large herbaceous vine	very rare	sandy organic soil
Sarcostemma clausa (Milkweed vine)	small to medium herbaceous vine	rare to abundant	sandy organic, sandy and rocky soil
Melothria pendula (Wild cucumber)	very small herbaceous vine	very rare to rare	sandy and rocky soil and debris
Momordica charantia (Wild balsam apple)	small herbaceous vine	very rare to rare	sandy soil
Cucurbita okeechobeensis (Indian pumpkin)	large herbaceous vine	very rare	sandy and rocky soil
Ipomoea alba (Moon vine)	massive, large woody liana	rare to abundant	sandy organic, sandy, and rocky soil

APPENDIX BB - VINES OF THE CYPRESS STRAND. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Hippocratea volubilis	large woody liana	abundant to very abundant	organic soil
Ampelopsis arborea (Pepper vine)	small woody to herbaceous vine	very rare to rare	sandy organic and organic soil
Parthenocissus quinquefolia (Virginia creeper)	small course herbaceous vine	rare to infrequent	sandy organic, sandy and rocky soil
Cissus sicyoides (Opossum grape)	small to large woody vine or liana	rare	organic and sandy organic soil
Vitis rotundifolia (Grape)	small to large woody liana	rare to infrequent	organic and sandy organic soil
Vitis aestivalis (Grape)	small to large woody liana	very rare to rare	organic and sandy organic soil
Toxicodendron radicans (Poison ivy)	small to large woody liana	abundant to very abundant	organic, sandy organic, sandy and rocky soil
Mikania batatifolia (Hemp vine)	small herbaceous vine	rare to abundant	sandy organic, sandy, and rocky soil, debris

APPENDIX CC - TERRESTRIAL HERBS OF THE CYPRESS STRAND (EXCLUDING VINES).

Key to Table

Abundance

very rare - less than 1 in 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 100

Growth habit

very small - less than 10 cm
small - 10 to 50 cm
medium - 50 to 100 cm
large - 100 to 200 cm
very large - over 200 cm

Genus species	Growth habit	Abundance	Substrate
Osmunda regalis (Royal fern)	medium to large	very rare to rare	sandy organic soil, debre
Campyloneurum phyllitidis (Strap fern)	medium	very rare to rare	debris
Nephrolepsis exaltata (Boston fern)	medium to large	rare to abundant	sandy organic soil and debris
Acrostichum danaeaefolium (Leather fern)	large	very rare	sandy organic
Pteridium aquilinum (Bracken fern)	medium to large	very rare	sandy organic, sandy and rocky soil
Blechnum serrulatum	medium	abundant to very abundant	sandy organic, sandy and rocky soil, debris
Woodwardia virginica (Virginia chain fern)	medium	very rare	sandy and rocky soil
Thelypteris kunthii (Swamp fern)	small to medium	infrequent to abundant	sandy organic soil and debris
Chloris neglecta (Finger grass)	medium to large	infrequent to abundant	sandy organic soil
Panicum sp. (Panic grass)	very small to small	very rare to rare	sandy organic soil and debris

APPENDIX CC - TERRESTRIAL HERBS OF THE CYPRESS STRAND (EXCLUDING VINES). CONT'D.

Genus species	Growth habit	Abundance	Substrate
Andropogon virginicus (Broom sedge)	medium to large	infrequent to abundant	sandy organic, sandy and rocky soil
Arundo donax (Giant reed)	large to very large	rare to infrequent	sandy organic, sandy and rocky soil
Tripsacum dactyloides (Grama grass)	large	very rare to rare	sandy organic, sandy and rocky soil
Cyperus plantifolius	medium to large	very rare to rare	sandy and rocky soil
Cladium jamaicensus (Saw grass)	medium to large	infrequent	sandy organic, sandy and rocky soil
Malaxis spicata (Ground orchid)	very small to small	very rare to rare	damp organic debris
Boehmeria cylindrica (Button hemp)	small to medium	infrequent	sandy and rocky soil debris
Kosteletzkya althaeifolia	medium to large	rare to infrequent	sandy soil
Lythrum lineare (Loose strife)	medium to large	infrequent	sandy organic, sandy and rocky soil
Asclepias incarnata (Milkweed)	medium to large	rare	sandy organic, sandy and rocky soil
Lantana camara	medium to large	very rare to rare	sandy organic soil
Callicarpa americana (French mulberry)	medium to large	rare	sandy organic soil
Lippia nodiflora (Capeweed)	very small	rare	organic, sandy organic soil
Hyptis alata (Bittermint)	medium to large	rare	sandy organic soil
Pluchea rosea (Marsh fleabane)	medium	rare	sandy and rocky soil
Pluchea purpurascens (Camphorweed)	medium	rare	sandy and rocky soil
Solidago angustifolia (Golden rod)	large	very rare to rare	sandy organic soil
Aster caroliniensis (Climbing aster)	large	very rare to rare	sandy organic and sandy soil

APPENDIX DD - EPIPHYTIC HERBS OF THE CYPRESS STRAND.

Key to Table

Abundance

very rare - less than 1 in 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

very small - less than 2 cm
small - 2 to 10 cm
medium - 10 to 20 cm
large - 30 to 100 cm
very large - over 100 cm

Genus species	Growth habit	Abundance	Substrate
Psilotum nudum (Wish fern)	medium	very rare to rare	Sabal and cypress
Vittaria lineata (Shoestring fern)	medium	very rare to rare	Sabal
Polypodium polypodiodes (Resurrection fern)	small to medium	very rare to rare	Pond apple and ash
Phlebodium aureum (Golden polypody)	medium to large	rare	Sabal
Tillandsia usneoides (Spanish moss)	large	very rare to rare	Cypress and hardwoods
Tillandsia fasciculata (Common wild pine)	large	abundant to very abundant	Cypress and hardwoods
Tillandsia setacea (Needle leaf bromeliad)	small	rare to infrequent	Cypress, pond apple, ash and other hardwoods
Tillandsia utriculata (Giant wild pine)	large to very large	very rare	hardwoods
Tillandsia circinata (Twisted wild pine)	small to medium	very rare to rare	Cypress, pond apple, ash and other hardwoods
Tillandsia balbisiana (Reflexed wild pine)	small to medium	very rare to rare	Cypress, pond apple, ash and other hardwoods

APPENDIX DD - EPIPHYTIC HERBS OF THE CYPRESS STRAND. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Tillandsia valenzuelana	small to medium	very rare to rare	Cypress, ash, pond apple and other small hardwoods
Harrisella porrecta (Orchid)	very small (leafless)	very rare	Wax myrtle
Polyrrhiza lindenii (Ghost orchid)	very small to small (leafless)	rare	Pond apple, ash and other hardwoods
Epidendrum anceps (Brown epidendrum)	medium to large	rare to infrequent	Pond apple, ash and other hardwoods
Epidendrum rigidum (Matted epidendrum)	small	rare to infrequent	Pond apple, ash and other hardwoods
Epidendrum difforme	small to medium	rare to infrequent	Pond apple, ash and other hardwoods
Encyclia tampensis (Butterfly orchid)	medium to large	infrequent to abundant	Pond apple, ash, other hardwoods and cypress
Encyclia cochleata (Shell orchid)	medium to large	very rare to rare	Pond apple, ash and other hardwoods

APPENDIX EE - AQUATIC HERBS OF THE CYPRESS STRAND OR CYPRESS SLOUGH.

Key to Table

Abundance

very rare - less than 1 in 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

small - less than 20 cm
medium - 20 to 100 cm
large - over 100 cm

Genus species	Growth habit	Abundance	Substrate
Rhynchospora inundata (Beak rush)	medium to large	very rare to rare	rooted emergent in standing water
Pontederia lanceolata (Pickerel weed)	medium to large	infrequent	rooted emergent in standing water
Juncus polycephalus (Rush)	medium	very rare to rare	rooted emergent in shallow water
Sagitarria lancifolia (Arrowhead)	medium to large	infrequent	rooted emergent in standing water
Sagittaria graminea (Arrowhead)	small to medium	rare to infrequent	rooted emergent or emergent
Saururus cernuus (Lizard's tail)	medium to large	rare to infrequent	rooted emergent in standing water or soggy soil
Polygonum hydropiperoides (Smartweed)	medium to large	rare to infrequent	rooted emergent in shallow to moderately deep water
Nasturtium officinale (Water cress)	medium to large	very rare to rare	rooted submergent or emergent in shallow water
Ludwigia repens	small to medium	abundant to very abundant	rooted submergent in shallow to moderately deep water
Proserpinaca palustris (Mermaid weed)	small	infrequent to abundant	rooted emergent or submergent in shallow water or soggy soil

APPENDIX EE - AQUATIC HERBS OF THE CYPRESS STRAND OR CYPRESS SLOUGH. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Centella erecta	small	infrequent to abundant	rooted emergent in soggy soil
Hydrocotyle umbellata	small	very rare to rare	rooted emergent in soggy soil or shallow water
Bacopa caroliniana	small to medium	infrequent to abundant	rooted submergent in shallow to moderately deep water
Utricularia inflata (Bladder wort)	small	very rare to rare	free-floating in shallow to moderately deep water
Diodia virginiana (Button weed)	small	infrequent to abundant	rooted emergent in soggy soil or very shallow water

APPENDIX FF - PRAIRIE PLANTS.

Key to Table

Abundance

very rare - less than 1 per 1000 individuals
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

very small - less than 10 cm
small - 10 to 50 cm
medium - 50 to 100 cm
large - 100 to 200 cm
very large - over 200 cm

Monocots of the Prairie

Genus species	Growth habit	Abundance	Location
Sagittaria lancifolia (Arrowhead)	medium to large emergent aquatic	very rare to rare	prairie and prairie depressions
Sagittaria graminea (Arrowhead)	small to medium submergent or emergent aquatic	rare	prairie and prairie depressions
Muhlenbergia capillaris	medium to large	abundant to very abundant	throughout prairie, prairie depressions and elevations
Spartina bakerii (Cord grass)	medium to large	infrequent	prairie and prairie depressions
Setaria corrugata (Foxtail grass)	small to medium	infrequent to abundant	prairie and prairie elevations
Panicum hemitomen (Maiden cane)	medium to large emergent aquatic	very rare to rare	prairie depressions
Andropogon virginicus (Broom sedge)	large	infrequent	prairie and prairie elevations
Andropogon sp.	medium to large	infrequent	prairie and prairie elevations
Manisuris rugosa (Necklace grass)	small to medium	rare to infrequent	prairie and prairie elevations

APPENDIX FF - PRAIRIE PLANTS. CONT'D.

Genus species	Growth habit	Abundance	Location
Eleocharis cellulosa (Spike rush)	small to medium emergent aquatic	very rare to rare	prairie and prairie depressions
Eleocharis atropurpurea	very small to small	rare to infrequent	prairie
Fuirena longa	small to medium	infrequent	prairie
Dichromena colorata (White-eyed grass)	small	infrequent	prairie
Cladium jamaicensis (Saw grass)	large	infrequent to abundant	prairie and prairie depressions
Rhynchospora inundata (Beak rush)	medium to large emergent aquatic	very rare to rare	mostly prairie depressions
Rhynchospora sp.	medium	rare to infrequent	prairie
Schoenus nigricans	medium to large	infrequent to abundant	throughout prairie and in prairie depressions
Xyris sp.	small to medium	very rare	prairie
Pontederia lanceolata	medium to large emergent aquatic	very rare	prairie depressions
Juncus biflorus	medium to large	very rare to rare	prairie and prairie depressions
Juncus polycephalus	medium to large emergent aquatic	rare to infrequent	prairie and prairie depressions
Hypoxis juncea	very small to small	very rare	prairie
Aletris lutea	medium	very rare	prairie and prairie elevations
Hymenocallis palmeri (Spider lily)	small to medium	infrequent to abundant	prairie
Crinum americanum (Swamp lily)	small to medium	rare to infrequent	prairie
Sisyrinchium sp.	small to medium	infrequent to abundant	prairie

APPENDIX FF - PRAIRIE PLANTS. CONT'D.

Genus species	Growth habit	Abundance	Location
Calopogon pulchellus (Marsh pink orchid)	medium to large	very rare to rare	prairie
Spiranthes laciniata (Lady's trusses orchid)	medium	very rare	prairie

Dicots of the Prairie

Genus species	Growth habit	Abundance	Location
Cassytha filiformis (Love vine)	small parasitic vine	infrequent to abundant	prairie and prairie elevations
Polygala baldwinii	small	very rare to rare	prairie and prairie elevations
Polygala grandiflora	small	rare to infrequent	throughout prairie
Linum carteri variety smallii	very small to small	very rare to rare	scattered through the prairies
Stillingia sylvatica	small to medium to large	very rare to rare	throughout prairie
Proserpinaca palustris	small emergent or submergent aquatic	very rare to rare	prairie and prairie depressions
Eryngium aromaticum	medium	very rare to rare	prairie
Eryngium yuccifolium	medium	rare to infrequent	prairie
Eryngium prostratum	small vine like herb	very rare	prairie elevations
Centella erecta	very small	rare to infrequent	prairie and prairie depressions
Oxypolis filiformis	medium to large	rare to infrequent	throughout prairie
Sabatia grandiflora	small	rare (seasonal)	throughout prairie
Sabatia bartramii	small to medium	very rare (seasonal)	throughout prairie
Asclepias longifolia (Milkweed)	slender medium in height	very rare (seasonal)	throughout prairie

APPENDIX FF - PRAIRIE PLANTS. CONT'D.

Genus species	Growth habit	Abundance	Location
Asclepias lanceolata (Milkweed)	slender medium to large in height	very rare to rare (seasonal)	throughout prairie
Asclepias incarnata (Milkweed)	medium to large	very rare	mostly low areas of prairie
Heliotropium polyphyllum	very small to small	infrequent (seasonal)	throughout prairie and prairie elevations
Physostegia denticulata	medium	very rare	mostly prairie elevations
Bacopa caroliniana	very small to small submergent aquatic	rare (seasonal)	mostly prairie depressions and low lying prairies
Buchnera elongata	small	infrequent	mostly elevated prairies near pinelands
Agalinis purpurea	medium	very rare (seasonal)	mostly elevated prairies near pinelands
Elytraria coroliniensis variety angustifolia	small	rare to infrequent (seasonal)	mostly near pinelands on drier elevated prairies
Borreria terminalis	medium	very rare (seasonal)	mostly elevated prairies near pinelands
Lobelia glandulosa	small to medium	infrequent to abundant	common throughout the prairies
Pluchea rosea	small to medium	very rare to rare	mostly on drier prairies
Pluchea purpurascens	small to medium	rare	mostly on drier prairies
Rudbechia sp.	small	very rare to rare	mostly near pinelands
Coreopsis leavenworthii	small to medium	rare to infrequent	throughout all prairies
Solidago angustifolia (Goldenrod)	large	very rare to rare (seasonal)	mostly near cypress strands

APPENDIX FF - PRAIRIE PLANTS. CONT'D.

Genus species	Growth habit	Abundance	Location
Solidago sp. (Goldenrod)	large to very large	generally very rare	extensive in some prairies
Mikania batatifolia (Hemp vine)	extensive herbaceous vine	rare to infrequent	widely scattered in all prairies
Liatrus garberi (Blazing star)	small to medium	very rare (seasonal)	mostly near pinelands or palm hammocks
Vernonia blodgettii (Ironweed)	medium to large	very rare	mostly drier rocky or sandy sites near pinelands
Cirsium horridulum (Giant thistle)	medium to large, very stout	very rare to rare (seasonal)	scattered over most prairies
Flaveria latifolia (Rabbit weed)	small to medium	infrequent to abundant	found in patches on most prairies particularly the drier areas
Eupatorium mikanioides	small to medium	very rare to rare	mostly on drier prairies

APPENDIX GG - TREES AND SHRUBS OF THE SANDY MARL PINE AND PALM ASSOCIATIONS.

Key to Table

Abundance

very rare - less than 1 per 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

large tree - over 10 meters
tree - 5 to 10 meters
small tree - 3 to 5 meters
large shrub - 2 to 3 meters
shrub - 1 to 2 meters
small shrub - less than 1 meter

Genus species	Growth habit	Abundance	Substrate
Pinus elliottii var. densa (Slash pine)	medium to large tree	abundant to very abundant	soil
Sabal palmetto (Cabbage palm)	small, medium or large tree	abundant to very abundant	soil
Serenoa repens (Saw palmetto)	low growing prostrate shrub	infrequent to abundant	higher more elevated soil
Myrica cerifera (Wax myrtle)	medium shrub, large shrub to small tree	infrequent, abundant to very abundant	soil
Ficus aurea (Fig)	small shrub to small tree	very rare to rare	soil, debris piles and often epiphytic on the Sabal palmetto
Magnolia virginiana (Sweet bay)	medium shrub, large shrub to small tree	very rare to rare	soil, often more elevated soil
Persea borbonia (Red bay)	medium to large shrub	very rare, rare to infrequent	soil
Ilex cassine (Dahoon holly)	large shrub, small tree or medium tree	very rare (mostly on the pine and palm islands of prairies)	soil, often more elevated soil

APPENDIX GG - TREES AND SHRUBS OF THE SANDY MARL PINE AND PALM ASSOCIATIONS. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Ilex glabra (Holly)	medium shrub	very rare (mostly on the pine and palm islands of prairies)	soil, often more elevated soil
Lyonia ferruginea	medium to large shrub	very rare (mostly on the pine and palm islands of prairies)	soil
Myrsine quianensis	medium to large shrub	rare to infrequent	soil
Bumelia reclinata	large shrub, small tree, or medium tree	very rare to rare	mostly on more elevated soil
Baccharis halimifolia (Sea myrtle)	small, medium, or large shrub	rare, infrequent or abundant	soil

APPENDIX HH - HERBACEOUS PLANTS OF THE WET PINE AND PALM ASSOCIATIONS.

Key to Table

Abundance

very rare - less than 1 per 1000
rare - 1 to 5 per 1000
infrequent - 5 to 50 per 1000
abundant - 50 to 500 per 1000
very abundant - over 500 per 1000

Growth habit

very large - over 200 cm
large - 100 to 200 cm
medium - 50 to 100 cm
small - 10 to 50 cm
very small - less than 10 cm

Genus species	Growth habit	Abundance	Substrate
Phlebodium aureum (Golden polypody fern)	small to medium	very rare to rare	epiphytic on *Sabal palmetto*
Blechnum serrulatum (fern)	small to medium	very rare to rare	sandy organic soil, prefers some shade
Muhlenbergia capillaris	medium	abundant	soil, prefers sun
Setaria geniculata (Foxtail grass)	small to medium	infrequent to abundant	soil, prefers some direct sunlight
Paspalum monostachyum	medium	abundant	soil, prefers a well lighted area
Andropogon virginicas (Broom sedge)	medium to large	very rare to rare	soil, tolerates partial shade
Andropogon sp.	medium	rare	soil, tolerates some shade
Manisuris rugosa (Necklace grass)	medium	rare to infrequent	soil, prefers sun
Dichromena colorata	small to medium	very rare to rare	mostly rocky sandy areas, tolerates partial shade

APPENDIX HH - HERBACEOUS PLANTS OF THE WET PINE AND PALM ASSOCIATIONS. CONT'D.

Genus species	Growth habit	Abundance	Substrate
Rhynchospora grayii	medium	rare to infrequent	mostly rocky, sandy soil, prefers sun
Tillandsia fasciculata (Common wild pine)	small to medium	very rare to rare	epiphytic on pine
Tillandsia balbisiana (Reflexed wild pine)	small	very rare to rare	epiphytic on pine
Smilax laurifolia (Green brier)	woody vine	very rare to rare	mostly on shrubs and small trees
Aletris lutea	small to medium (leaves basal)	very rare	mostly in sunny areas
Polygala grandiflora	small to medium	rare to infrequent	mostly sunny to partly shaded areas
Kosteletzkya althalifolia	medium to large	very rare to rare	tolerates some shade
Eryngium yuccifolium	medium	rare, infrequent to abundant	tolerates moderate shade, prefers some direct light
Eryngium prostratum	very small to small, somewhat viney at times	very rare to rare	mostly on rocky surfaces, needs some sun
Centella erecta	very small	very rare to rare	tolerates shade, needs moisture
Sabatia grandiflora	small to medium (slender herb)	rare to infrequent (seasonal)	soil needs good light
Trichostema dichotomum	medium to large	very rare	needs good light
Buchnera elongata	small	rare to infrequent (varies seasonally)	needs some direct light
Hedyotis fasiculata	small slender herb	very rare	shallow soil, needs good light
Elytraria caroliniensis variety angustifolia	small	very rare	shallow soil, needs some direct sun

APPENDIX HH - HERBACEOUS PLANTS OF THE WET PINE AND PALM ASSOCIATIONS. CONT'D.

Genus species	Growth habits	Abundance	Substrate
Lobelia glandulosa	small to medium (slender herb)	rare (seasonal)	shallow rocky soil, needs sun
Coreopsis leavenworthii	small	very rare to rare (varies seasonally)	shallow soil, needs sun
Melanthera aspera var. glabriuscula	medium to large	very rare	sandy soil, needs sun
Rudbeckia fulgida (Coneflower)	medium	rare to infrequent (varies seasonally)	soil, tolerates partial shade
Pluchea rosea (Marsh fleabane)	medium	very rare	mostly on shallow rocky soil, needs sun
Pluchea purpurascens (Camphorweed)	medium	very rare	mostly on shallow rocky soil, needs sun
Mikania batatifolia (Hemp vine)	slender herbaceous vine	rare to infrequent	soil tolerates partial shade
Liatrus garberi (Blazing star)	medium to large	very rare	sandy soil, needs sun
Eupatorium mikanioides	medium	very rare	mostly shallow rocky soil, needs sun

APPENDIX II - AQUATIC PLANTS OF THE DITCHES AND CANALS.

Genus species	Water depth	Water velocity	Seasonal flux	Bottom type	Station
Azolla caroliniana (red water fern)	1 meter or more	sluggish	cannot tolerate exposure	free floating aquatic	Misc.
Salvinia rotundifolia (water fern)	1 meter or more	sluggish	cannot tolerate exposure	free floating	Misc.
Typha angustifolia (narrow leaf cattail)	less than 1 meter	sluggish to moderate ditches, canals and margins	tolerates seasonal exposure	emergent, deeply rooted in soft mud or organic bottoms	GAC, JD, TC, AA, Misc.
Typha latifolia (broad leaf cattail)	less than 1 meter	sluggish	tolerates brief seasonal exposure	emergent, deeply rooted in soft mud or organic bottoms	Misc.
Potamogeton illinoensis (pondweed)	0.1-2.0 meters	sluggish to moderate	cannot tolerate exposure	Submergent rooted in sandy or sandy mud bottoms	AA
Najas quadalupensis (naiad)	0.5-3.0 meters	sluggish moderate or swift	cannot tolerate exposure	variable sandy, rocky or sandy muds	GAC, JD, TC, AA, Misc.
Sagittaria lancifolia (arrowhead)	less than 0.5 meters	sluggish canal, ditches and margins	tolerates exposure, requires only moist soil	emergent rooted in sandy soil, sandy muds or organic bottoms	GAC, JD, TC, AA, Misc.
Sagittaria graminea (arrowhead)	less than 1.0 meters	sluggish to moderate	tolerates exposure	emergent or submergent rooted in sandy rocky, sandy mud, or organic soils	GAC JD, TC, AA, Misc.
Zizaniopsis miliacea (giant cutgrass)	less than 0.5 meters	sluggish margins	tolerates exposure	emergent rooted in sandy organic, to organic soil	JD, Misc.
Phragmites australis (reed)	less than 0.5 meters	sluggish margins (also along banks)	tolerates continuous exposure	emergent aquatic and on banks rooted in sandy, sandy mud, and sandy organic soils	GAC, JD, TC, AA, Misc.
Panicum hemitomen (maidencane)	less than 0.5 meters	sluggish canals, ditches and margins (also along banks)	tolerates continuous exposure	emergent and on banks rooted in sandy, rocky and sandy organic soils and muds	JD, TC, AA, Misc.
Cyperus haspan (sedge)	less than 0.2 meters	sluggish margins and on banks	tolerates continuous exposure	emergent or on banks rooted in sandy, rocky soils and muds	GAC
Eleocharis acicularis	less than 0.5 meters	sluggish margins	tolerates brief exposure	sandy organic muds emergent or submergent	GAC (at the weir)
Cladium jamaicensis (sawgrass)	less than 1.0 meters	sluggish margins or shallows	tolerates exposure (exposure required for seedling growth and germination)	emergent rooted in sandy organic muds and organic soils	JD, AA, Misc.
Rhynchospora inudata (beakrush)	less than 1.0 meters	sluggish margins or shallows	tolerates exposure	emergent rooted in sandy, sandy organic or organic soils and muds	GAC, JD, Misc.
Lemna perpusilla (duckweed)	over 1 meter	sluggish canals and ditches	cannot tolerate exposure	free floating aquatic	Misc.
Eichhornia crassipes (water hyacinth)	over 1 meter	sluggish to moderate canals and ditches	cannot tolerate exposure	free floating aquatic (often webbed across the surface of a canal)	TC (near agricultural activities)

APPENDIX II - AQUATIC PLANTS OF THE DITCHES AND CANALS. CONT'D.

Genus species	Water depth	Water velocity	Seasonal flux	Bottom type	Station
Pontederia lanceolata (pickeralweed)	less than 0.5 meters	sluggish canals, ditches and margins	tolerates exposure	emergent rooted in sandy organic and organic soils and muds	JD, AA, Misc.
Juncus polycephalus (rush)	less than 0.5 meters	sluggish margins and ditches	tolerates continuous exposure	emergent rooted in sandy and sandy organic bottoms, margins, and on banks	GAC, JD, Misc.
Canna flaccida (wild canna)	less than 1.0 meters	sluggish margins and ditches	tolerates exposure	emergent in sandy organic and organic soils	JD, Misc.
Thalia geniculata (fire flag)	less than 1.0 meters	sluggish margins and ditches	tolerates exposure	emergent rooted in sandy organic and organic soils	JD, AA, Misc.
Saururus cernuus (lizzard's tail)	less than 0.5 meters	sluggish ditches	tolerates brief seasonal exposure	emergent in sandy organic or organic soils and muds	JD
Polygonum hydropiperoides (smartweed)	less than 1.0 meters	sluggish ditches and margins	tolerates seasonal exposure	emergent in organic soils and muds	JD, Misc.
Nymphaea oderata (white waterlily)	over 1 meter	sluggish to moderate	cannot tolerate exposure	emergent with floating leaves, rooted in organic soil or mud	JD, AA,
Nymphaea elegans (Blue waterlily)	over 1 meter	sluggish to moderate	cannot tolerate exposure	emergent with floating leaves rooted in organic soil or mud	JD
Ludwigia repens	less than 1 meter	sluggish to moderate	tolerates seasonal exposure	submergent or emergent rooted in sand, rocky organic soils and muds	GAC, JD, Misc.
Ludwigia peruviana (water primrose)	less than 0.5 meters	sluggish ditches and margins mostly on banks	tolerates exposure	sandy, sandy organic and organic soils	GAC, JD, TC, AA, Misc.
Ludwigia leptocarpa (water primrose)	less than 0.5 meters	sluggish ditches	tolerates exposure	sandy, sandy organic, and organic soils	JD, Misc.
Myriophyllum brasiliense (water milfoil)	over 0.5 meters	moderate to swift	cannot tolerate long exposure	sandy, rocky, and organic soils and muds, submergent	GAC
Proserpinaca palustris (mermaid weed)	less than 1.0 meters	sluggish margins and shallow ditches (also on banks)	tolerates continuous exposure	emergent or submergent in sandy rocky, and organic soils and muds	GAC JD, AA, Misc.
Bacopa caroliniana	less than 1.0 meters	sluggish to moderate margins and shallow ditches	tolerates very brief exposure	submergent rooted in sandy, or organic soils and muds	GAC JD, AA, Misc.
'tricularia foliosa bladderwort)	over 1.0 meters	sluggish margins and ditches	cannot tolerate exposure	free floating aquatic	GAC, JD, AA, Misc.
Jtricularia purpurea (purple flowered bladderwort)	over 1.0 meters	sluggish margins and ditches	cannot tolerate exposure	free floating	GAC, JD, Misc.
Dioda virginiana (buttonweed)	less than 1.0 meters	sluggish to moderate ditches and margins (also on banks)	Must be exposed seasonally for flowering	Submergent or emergent (seasonal) and on dry banks, sandy, sandy organic soils and muds	JD, Misc.

APPENDIX JJ - ABUNDANCE OF MACROBENTHOS (INDIVIDUALS PER 0.046 M^2).

FAHKAHATCHEE BAY (MARCH 28-30, 1972)

	Grid Locations										Grid Locations										Grid Locations					
	Mud Substrate										Sand										Shell					
ORGANISMS	Q-6	C-5	D-/	F-8	G-7	I-6	K-5	K-7	M-6	N-4	E-1	E-3	E-5	G-3	G-5	I-4	J-2	J-3	L-2	L-4	G-0	G-1	H-0	I-3	K-2	M-3
Arthropoda																										
Crustacea																										
Malacostraca																										
Amphipoda	6	21	305	10	32	4	374	195	458	130	11	403	10	920	6	14	461	628	70	14	13	19	9	59	203	9
Isopoda	611	55	28	10	6	1	38		50	575	7	1	6	138	1	1	6	80	69	12	7	4	1	5	9	4
Cumacea	1		2								1			69											1	
Thoracica																										1
Decapoda	1	1						1			1				1	2	1	4	1	5	10		2	13	1	5
Ostracoda	1						14							43			22	13				1			5	
Insecta																										
Ephemeroptera																										
Baetidae																					1					
Diptera																										
Chironomidae				12																	2					
Tendipedidae									2																	
Trichoptera																										
Psychomyildae																					42					
Annelida																										
Polychaeta	20	8	13	2	5	8	1C	10	13	13	4	2	1	21	4	10	40	26	1	4	2	1	8	2	64	29
Rhynchocoela		5	'3	3	5		7	1				2		15	4	10	8	10					10		7	2
Mollusca																										
Gastropoda	1					1			43	2		1				2	1	1						1		
Amphineura																							1			
Pelecypoda	18	11	17	14	1	2		1	9	5				52	4		2	13	1			2		1	1	22
Echinodermata																										
Ophiuroidea			2															1	1						1	
Porifera																					1	2				

FAHKA UNION BAY (MARCH 28-30, 1972)

	Grid Locations						Grid Locations						Grid Locations					
	Mud Substrate						Sand						Shell					
ORGANISMS	P-8	P-10	Q-11	Q-12	R-11	R-12	S-9A	S-9B	P-9A	P-9B	S-10A	S-10B	T-10A	T-10B	T-10C	U-12A	U-12B	U-12C
Arthropoda																		
Crustacea																		
Malacostraca																		
Amphipoda	22	23	1	1	7	1	6	5	9	4	56	49	4	24	248	10	202	7
Isopoda	282	644	148	195	684	36	114	186	498	102	590	19	145	153	140	165	.	91
Cumacea													2		2	1	1	
Mysidacea		1						1		1								
Decapoda		2	1						1		1		3	1.				3
Ostracoda											2		8		1			
Copepoda		1									4							
Insecta																		
Diptera	2		1	1					1									
Annelida																		
Polychaeta	5	5	2	4	4	1	2	34	3	13	74	44	36	27		3	4	2
Hirudinea											1							
Rhynchocoela	2	7	1		1			6		5	8	6	4	1		1	8	1
Mollusca																		
Gastropoda	1										12		1					
Pelycepoda	23	35	11	5	2		1	2	15	7	11	1	1	1	2			1
Chordata																		
Ascidiacea	3	3			1				2	1								

APPENDIX JJ - ABUNDANCE OF MACROBENTHOS (INDIVIDUALS PER 0.046 M^2). CONT'D.

FAHKAHATCHEE BAY (JUNE 20-21, 1972)

ORGANISMS	Grid Locations Mud Substrate										Grid Locations Sand										Grid Locations Shell					
	Q-6	[illegible]-5	D-7	F-8	G-7	I-6	K-5	K-7	M-6	N-4	E-1	E-3	E-5	G-3	G-5	I-4	J-2	J-3	L-2	L-4	G-0	G-1	H-0	I-3	K-2	M-3
Arthropoda																										
Crustacea																										
Malacostraca																										
Amphipoda	17	12	12	1	7	8	10	9	13	9	126	20	13	33	25	2	1	219	4	171	58	62	22	20	5	18
Isopoda	889	2	49	2	3	8	5	1	2	527	12	12	5	647		1	6	143	3	61	454	445	23	80	9	76
Cumacea							1		1	2	4		1	1						1	4	1				1
Mysidacea													1													
Thoracica			1																							
Decapoda					6		2	1	2	1	3	1		6	1	2	1	1		3	1	2	3	3	1	
Ostracoda Copepoda											4			[illegible]								15				
Insecta																										
Diptera	1																	1								
Annelida																										
Polychaeta	6	16	8	3	5	12	17	10	15	16	26	20	27	27	8	7	1	70	2	7	9	23	11	24	2	13
Rhynchocoela	2	12	2	5			1	1		1						3		4					1	1		3
Mollusca																										
Gastropoda	1		4		2	6	6	10			3			1		2	5	1	7				11		23	
Amphineura																					1		1			
Pelecypoda	10	3	1	2	5	3		2	1		5	1	1					6	4		1	3	5			
Echinodermata																										
Ophiuroidea									1		2															
Porifera																		3								
Chordata																										
Ascidiacea	1			1																						
Osteichthyes									1				1													
Acanthocephala		2																								

FAHKA UNION BAY (JUNE 20-21, 1972)

ORGANISMS	Grid Locations Mud Substrate						Grid Locations Sand						Grid Locations Shell					
	P-8	P-10	Q-11	Q-12	R-11	R-12	S-9A	S-9B	P-9A	P-9B	S-10A	S-10B	T-10A	T-10B	T-10C	U-12A	U-12B	U-12C
Arthropoda																		
Crustacea																		
Malacostraca																		
Amphipoda	283		44	11	56	68	41	7	10	29	18	38	13	11	10	12	7	7
Isopoda	39	284	1229	96'	1358	1172	483	803	818	148	120	85	19	206	6	932	236	786
Cumacea			1			1												
Mysidacea								1										
Decapoda			4	3	1			1	1		2		1	8	1	1		
Annelida																		
Polychaeta		2	10		34	17	14	23	34	7	14	45	57	21	44	33	10	4
Rhynchocoela	1		1				1		5		3	3	2		2		2	3
Mollusca																		
Gastropoda	1	1	1	1		18			5									
Pelecypoda	3	20	10	11	4	12	3	1	15		1	3	1				1	3
Echinodermata																		
Ophiuroidea					1													

APPENDIX JJ - ABUNDANCE OF MACROBENTHOS (INDIVIDUALS PER 0.046 M^2). CONT'D.

FAHKAHATCHEE BAY (SEPTEMBER 25-28, 1972)

	Grid Locations										Grid Locations										Grid Locations					
	Mud Substrate										Sand										Shell					
ORGANISMS	Q-6	C-5	D-7	F-8	G-7	I-6	K-5	K-7	M-6	N-4	E-1	E-3	E-5	G-3	G-5	I-4	J-2	J-3	L-2	L-4	G-0	G-1	H-0	I-3	K-2	M-3
Arthropoda																										
Crustacea																										
Malacostraca																										
Amphipoda	202	6	7		32	194	3	5	55	189	4	2	9	1	7	2	59	7	12	9			12	13	6	21
Isopoda	33				1	8				6					1	2	4		12		1		2	4	92	7
Cumacea						2						1		1												
Mysidacea																1										
Tanaidacea	398					448				41	3	2								3						
Decapoda	1	4				3	3		3	3	4	3	7	5	4		4	3	4	2	2	1	4	8	4	
Annelida																										
Polychaeta	8	43	8		13	19	13	1	2	4	28	44	25	21	24	8	1	26	22	25	2	4		6	1	4
Oligochaeta						2			9	1	11	14			10				4	10				1		
Mollusca																										
Gastropoda	6			1	14		1						4	4	7	13	32	2	7		1		58	1	10	
Amphineura																					2		2			
Pelecypoda	2		1		2				3				1		3					1	3				1	
Echinodermata																										
Ophiuroidea			1						1		1		1					1								1
Ectoprocta				2																						
Sipunculida				1			4			8	2			3				3	6	7						
Porifera																					1	3				

FAHKA UNION BAY (SEPTEMBER 25-28, 1972)

	Grid Locations						Grid Locations						Grid Locations					
	Mud Substrate						Sand						Shell					
ORGANISMS	P-8	P-10	Q-11	Q-12	R-11	R-12	S-9A	S-9B	P-9A	P-9B	S-10A	S-10B	T-10A	T-10B	T-10C	U-12A	U-12B	U-12C
Arthropoda																		
Crustacea																		
Malacostraca																		
Amphipoda	152	118	303	117	44	166	317	202	74	147	45	5	1	83	26	13	218	72
Isopoda	1		25		8	47	11	70	18	2	18	1		12	9	7	9	22
Cumacea										1				1				
Tanaidacea	118		69	229	67	28	130	29		10	10			17	49	53	273	39
Decapoda	2	1			1	5		2		1	3		1	1	7	1	1	
Insecta																		
Diptera																		
Ceratopogonidae							1											
Chironomidae									1					1		1		
Collembola																6		
Annelida																		
Polychaeta	4	1	3			1	16	16	4	1	10	7	6	14	8	1	8	4
Oligochaeta	3									1	5		25					
Mollusca																		
Gastropoda				7				1		3		4		1	4			
Pelecypoda		7	7	4	1			7	9	1	19	6		1		7	2	1
Sipunculida	4							3		1					4	4		
Rhynchocoela										2			6		1			

APPENDIX KK - LIST OF SCIENTIFIC AND COMMON NAMES OF FISHES FROM FAHKAHATCHEE STRAND AND TEN THOUSAND ISLANDS, FLORIDA, 1972.

Family	Species	Common name
Carcharhinidae	Carcharhinus leucas	Bull shark
	Carcharhinus limbatus	Blacktip shark
	Negaprion brevirostris	Lemon shark
Sphyrnidae	Sphyrna tiburo	Bonnethead
Dasyatidae	Dasyatis americana	Southern stingray
	Dasyatis sabina	Atlantic stingray
	Gymnura micrura	Smooth butterfly ray
Myliobatidae	Aetobatus narinari	Spotted eagle ray
Lepisosteidae	Lepisosteus platyrhincus	Florida gar
Amiidae	Amia calva	Bowfin
Elopidae	Elops saurus	Ladyfish
	Megalops atlantica	Tarpon
Ophichthidae	Myrophis punctatus	Speckled worm eel
Clupeidae	Brevoortia patronus	Gulf menhaden
	Brevoortia smithi	Yellowfin menhaden
	Harengula pensacolae	Scaled sardine
	Opisthonema oglinum	Atlantic thread herring
Engraulidae	Anchoa cubana	Cuban anchovy
	Anchoa hepsetus	Striped anchovy
	Anchoa mitchilli	Bay anchovy
Synodontidae	Synodus foetens	Inshore lizardfish
Cyprinidae	Notemigonus crysoleucas	Golden shiner
	Notropis maculatus	Taillight shiner
Catostomidae	Erimyzon sucetta	Lake chubsucker
Ictaluridae	Ictalurus natalis	Yellow bullhead
	Ictalurus nebulosus	Brown bullhead
Ariidae	Arius felis	Sea catfish
	Bagre marinus	Gafftopsail catfish
Batrachoididae	Opsanus beta	Gulf toadfish
Gobiesocidae	Gobiesox strumosus	Skilletfish

APPENDIX KK - LIST OF SCIENTIFIC AND COMMON NAMES OF FISHES FROM FAHKAHATCHEE STRAND AND TEN THOUSAND ISLANDS, FLORIDA, 1972. CONT'D.

Family	Species	Common name
Ogcocephalidae	Ogcocephalus radiatus	Polka-dot batfish
Exocoetidae	Hyporhamphus unifasciatus	Halfbeak
Belonidae	Strongylura marina	Atlantic needlefish
	Strongylura notata	Redfin needlefish
	Strongylura timucu	Timucu
	Tylosurus crocodilus	Houndfish
Cyprinodontidae	Adinia xenica	Diamond killifish
	Cyprinodon variegatus	Sheepshead minnow
	Floridichthys carpio	Goldspotted killifish
	Fundulus chrysotus	Golden topminnow
	Fundulus confluentus	Marsh killifish
	Fundulus grandis	Gulf killifish
	Fundulus seminolis	Seminole killifish
	Fundulus similis	Longnose killifish
	Jordanella floridae	Flagfish
	Lucania goodei	Bluefin killifish
	Lucania parva	Rainwater killifish
Poeciliidae	Gambusia affinis	Mosquitofish
	Heterandria formosa	Least killifish
	Poecilia latipinna	Sailfin molly
Atherinidae	Labidesthes sicculus	Brook silverside
	Membras martinica	Rough silverside
	Menidia beryllina	Tidewater silverside
Syngnathidae	Hippocampus erectus	Lined seahorse
	Hippocampus reidi	Longsnout seahorse
	Hippocampus zosterae	Dwarf seahorse
	Syngnathus floridae	Dusky pipefish
	Syngnathus louisianae	Chain pipefish
	Syngnathus scovelli	Gulf pipefish
	Syngnathus springeri	Bull pipefish
Centropomidae	Centropomus parallelus	Fat snook
	Centropomus pectinatus	Tarpon snook
	Centropomus undecimalis	Snook
Serranidae	Diplectrum formosum	Sand perch
	Epinephelus itajara	Jewfish
	Mycteroperca microlepis	Gag
Centrarchidae	Elassoma evergladei	Everglades pygmy sunfish
	Enneacanthus gloriosus	Bluespotted sunfish

APPENDIX KK - LIST OF SCIENTIFIC AND COMMON NAMES OF FISHES FROM FAHKAHATCHEE STRAND AND TEN THOUSAND ISLANDS, FLORIDA, 1972. CONT'D.

Family	Species	Common name
Centrarchidae - Contd.	*Lepomis gulosus*	Warmouth
	Lepomis macrochirus	Bluegill
	Lepomis marginatus	Dollar sunfish
	Lepomis microlophus	Redear sunfish
	Lepomis punctatus	Spotted sunfish
	Micropterus salmoides	Largemouth bass
Percidae	*Etheostoma fusiforme*	Swamp darter
Rachycentridae	*Rachycentron canadum*	Cobia
Echeneidae	*Echeneis neucratoides*	Whitefin sharksucker
Carangidae	*Caranx crysos*	Blue runner
	Caranx hippos	Crevalle jack
	Chloroscombrus chrysurus	Atlantic bumper
	Oligoplites saurus	Leatherjacket
	Selene vomer	Lookdown
	Trachinotus carolinus	Florida pompano
	Trachinotus falcatus	Permit
Lutjanidae	*Lutjanus griseus*	Gray snapper
	Lutjanus synagris	Lane snapper
Gerreidae	*Diapterus olisthostomus*	Irish pompano
	Diapterus plumieri	Striped mojarra
	Eucinostomus argenteus	Spotfin mojarra
	Eucinostomus gula	Silver jenny
Pomadasyidae	*Orthopristis chrysoptera*	Pigfish
Sparidae	*Archosargus probatocephalus*	Sheepshead
	Lagodon rhomboides	Pinfish
Sciaenidae	*Bairdiella chrysura*	Silver perch
	Cynoscion arenarius	Sand seatrout
	Cynoscion nebulosus	Spotted seatrout
	Leiostomus xanthurus	Spot
	Menticirrhus americanus	Southern kingfish
	Menticirrhus saxatilis	Northern kingfish
	Pogonias cromis	Black drum
	Sciaenops ocellata	Red drum
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish
Scaridae	*Nicholsina usta*	Emerald parrotfish

APPENDIX KK - LIST OF SCIENTIFIC AND COMMON NAMES OF FISHES FROM FAHKAHATCHEE STRAND AND TEN THOUSAND ISLANDS, FLORIDA, 1972. CONT'D.

Family	Species	Common name
Mugilidae	Mugil cephalus	Striped mullet
	Mugil curema	White mullet
	Mugil trichodon	Fantail mullet
Sphyraenidae	Sphyraena barracuda	Great barracuda
Blenniidae	Blennius nicholsi	Highfin blenny
	Chasmodes saburrae	Florida blenny
Gobiidae	Bathygobius soporator	Frillfin goby
	Gobionellus shufeldti	Freshwater goby
	Gobiosoma bosci	Naked goby
	Gobiosoma robustum	Code goby
	Lophogobius cyprinoides	Crested goby
	Microgobius gulosus	Clown goby
	Microgobius thalassinus	Green goby
Trichiuridae	Trichiurus lepturus	Atlantic cutlassfish
Scombridae	Sarda sarda	Atlantic bonito
	Scomberomorus maculatus	Spanish mackerel
Triglidae	Prionotus scitulus	Leopard searobin
	Prionotus tribulus	Bighead searobin
Bothidae	Etropus crossotus	Fringed flounder
	Paralichthys albigutta	Gulf flounder
	Paralichthys lethostigma	Southern flounder
Soleidae	Achirus lineatus	Lined sole
	Trinectes maculatus	Hogchoker
Cynoglossidae	Symphurus plagiusa	Blackcheek tonguefish
Balistidae	Monacanthus hispidus	Planehead filefish
Ostraciidae	Lactophrys quadricornis	Scrawled cowfish
Tetraodontidae	Sphoeroides nephelus	Southern puffer
	Sphoeroides parvus	Least puffer
Diodontidae	Chilomycterus antillarum	Web burrfish
	Chilomycterus schoepfi	Striped burrfish

APPENDIX LL - SUMMARY OF SELECTED AQUATIC BIOTA ASSAYED FOR ASH-FREE DRY WEIGHT AND ORGANIC NITROGEN, FAHKAHATCHEE STRAND AND ADJACENT CANALS, FLORIDA, 1972.

Species	Date collected	Size range (mm)	Wet weight (gm)	Percent dry weight	Ash-free, percent of dry weight	Organic N, percent of dry weight
Fishes						
Lepisosteus platyrhincus	Feb. 2	384			68.5	7.6
Notemigonus crysoleucas	Feb. 28	62-104	13.7	19.7	84.0	9.6
Erimyzon sucetta	Feb. 28	34-68	26.7	18.0	82.6	9.4
Ictalurus natalis	Mar. 7	70		22.4	93.0	8.5
Ictalurus nebulosus	Apr. 4		589.0	23.3	86.3	11.4
Fundulus confluentus	Mar. 7	34-61	14.2	23.2	85.6	8.4
Fundulus seminolis	Feb. 28	123	14.5	24.8	84.2	9.5
Jordanella floridae	Jan. 12	17-33	50.2	19.9	82.9	9.2
Lucania goodei	Feb. 12	19-53	152.5	18.6	82.1	8.8
Gambusia affinis	Jan. 12	15-45	77.1	19.7	84.3	8.6
Heterandria formosa	Jan. 12	13-25	5.0	22.0	96.9	9.4
Poecilia latipinna	Mar. 7	23-51	37.6	24.5	86.9	7.8
Enneacanthus gloriosus	Feb. 28	46-52	19.0	17.9	77.2	9.1
Lepomis gulosus	Feb. 28	171	112.3	26.2	75.1	8.9
Lepomis macrochirus	Feb. 28	204	166.2	26.4	77.3	9.7
Lepomis microlepis	Feb. 28	45-120	210.8	21.1	76.0	9.9
Lepomis punctatus	Feb. 28	145-191	73.4	17.1	79.0	10.0
Amphibians						
Diemictylus viridescens	Feb. 8	37-74	5.8	12.1		8.0
Rana spp.	Jan. 12	21-50	8.4	11.9		8.6
Crustacean						
Procambarus alleni	Mar. 7	18-22[a]	197.4	20.4	68.1	8.0
Plants						
Saggittaria graminea	July 27		250.3	8.5	80.1	1.0
Cyperus spp.	July 27		15.0	11.3	86.8	1.3
Pontederia lanceolata	Jan. 12		527.5	7.2	78.6	1.4
Polygonum hydropiperoides	Jan. 12		813.0	25.1	93.8	0.6
Ludwigia repens	Jan. 13		660.0	5.7	77.6	1.1
Proserpinaca palustris	Jan. 12		57.6	22.2	72.4	0.9
Bacopa caroliniana	Feb. 8		90.0	10.1	74.6	1.4
Utricularia foliosa	Jan. 12		224.5	5.3	58.5	1.2
Diodia virginiana	Feb. 8		202.0	10.6	79.8	1.8
Mikania batatifolia	Jan. 12		234.9	32.9	85.3	0.9

[a] Measured from anterior orbit to posterior edge of carapace.

APPENDIX MM - SPATIAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972, BY HABITAT: (1) BEACHES AND ADJACENT WATERS IN THE LOWER REACHES; (2) BAYS IN THE MIDDLE REACHES; (3) TIDAL STREAMS AND (4) TIDAL CANALS IN THE UPPER REACHES; (5) FRESHWATER CANALS; AND (6) FRESHWATER LAKES, PONDS, AND TEMPORARY WATERWAYS IN FAHKAHATCHEE STRAND. SPECIES TAKEN IN THE MONTHLY COLLECTIONS AT THE REGULAR STATIONS ARE INDICATED BY THE LETTER X, WHEREAS PARENTHESIS DESIGNATE FISHES THAT WERE ONLY COLLECTED DURING OTHER INVESTIGATIONS.

SPECIES	HABITAT					
	1	2	3	4	5	6
Carcharhinus leucas				(X)		
Carcharhinus limbatus	(X)					
Negaprion brevirostris	X					
Sphyrna tiburo	(X)	X				
Dasyatis americana	X	(X)				
Dasyatis sabina	X	X				
Gymnura micrura	X					
Aetobatus narinari		X				
Lepisosteus platyrhincus			X	(X)	(X)	X
Amia calva					(X)	(X)
Elops saurus		X	X	X		
Megalops atlantica	(X)	(X)				
Myrophis punctatus		X	(X)	X		
Brevoortia patronus				(X)		
Brevoortia smithi	X	X	X	X		
Harengula pensacolae	X	X	X			
Opisthonema oglinum	X	X				
Anchoa cubana		X				
Anchoa hepsetus	X	X	X	X		
Anchoa mitchilli	X	X	X	X		
Synodus foetens	X	X	X	X		
Notemigonus crysoleucas				(X)	(X)	(X)
Notropis maculatus				(X)	(X)	
Erimyzon sucetta				(X)	(X)	
Ictalurus natalis				(X)	(X)	X
Ictalurus nebulosus						(X)
Arius felis	X	X	(X)			
Bagre marinus		X				
Opsanus beta		X				
Gobiesox strumosus		(X)				
Ogcocephalus radiatus	X	(X)				
Hyporhamphus unifasciatus	X	X				
Strongylura marina	X	X	X	X		
Strongylura notata	X	X	X	X		
Strongylura timucu	X	X	X	X		
Tylosurus crocodilus	X					
Adinia xenica			(X)	X		

APPENDIX MM - SPATIAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972, BY HABITAT: (1) BEACHES AND ADJACENT WATERS IN THE LOWER REACHES; (2) BAYS IN THE MIDDLE REACHES; (3) TIDAL STREAMS AND (4) TIDAL CANALS IN THE UPPER REACHES; (5) FRESHWATER CANALS; AND (6) FRESHWATER LAKES, PONDS, AND TEMPORARY WATERWAYS IN FAHKAHATCHEE STRAND. SPECIES TAKEN IN THE MONTHLY COLLECTIONS AT THE REGULAR STATIONS ARE INDICATED BY THE LETTER X, WHEREAS PARENTHESIS DESIGNATE FISHES THAT WERE ONLY COLLECTED DURING OTHER INVESTIGATIONS. CONT'D.

SPECIES	HABITAT					
	1	2	3	4	5	6
Cyprinodon variegatus			X	(X)		
Floridichthys carpio	X	X	X	X		
Fundulus chrysotus				(X)	(X)	X
Fundulus confluentus			X	X	(X)	X
Fundulus grandis			(X)	X		
Fundulus seminolis					(X)	
Fundulus similis	X	X				
Jordanella floridae				X	(X)	X
Lucania goodei			X	(X)	(X)	X
Lucania parva		X	X	X		
Gambusia affinis		X	X	X	(X)	X
Heterandria formosa				(X)	(X)	X
Poecilia latipinna			X	X	(X)	X
Labidesthes sicculus					(X)	
Membras martinica	X	X				
Menidia beryllina	X	X	X	X		
Hippocampus erectus	(X)	X				
Hippocampus reidi	(X)					
Hippocampus zosterae		X				
Syngnathus floridae		X				
Syngnathus louisianae	X	X				
Syngnathus scovelli	X	X	X	X		
Syngnathus springeri		X				
Centropomus parallelus				(X)		
Centropomus pectinatus	(X)					
Centropomus undecimalis	X	X	X	X		
Diplectrum formosum	X	(X)				
Epinephelus itajara		X				
Mycteroperca microlepis		X				
Elassoma evergladei				(X)	(X)	X
Enneacarthus gloriosus					(X)	
Lepomis gulosus			(X)	(X)	(X)	X
Lepomis machrochirus			(X)	(X)	(X)	X
Lepomis marginatus				(X)	(X)	
Lepomis microlophus				X	(X)	(X)
Lepomis punctatus				(X)	(X)	X
Micropterus salmoides				(X)	(X)	
Etheostoma fusiforme					(X)	
Rachycentron canadum	(X)					
Echeneis neucratoides	X	(X)				
Caranx crysos		(X)				
Caranx hippos	X	(X)		X		
Chloroscombrus chrysurus		X				
Oligoplites saurus	X	X	X	X		
Selene vomer		X				

APPENDIX MM - SPATIAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972, BY HABITAT: (1) BEACHES AND ADJACENT WATERS IN THE LOWER REACHES; (2) BAYS IN THE MIDDLE REACHES; (3) TIDAL STREAMS AND (4) TIDAL CANALS IN THE UPPER REACHES; (5) FRESHWATER CANALS; AND (6) FRESHWATER LAKES, PONDS, AND TEMPORARY WATERWAYS IN FAHKAHATCHEE STRAND. SPECIES TAKEN IN THE MONTHLY COLLECTIONS AT THE REGULAR STATIONS ARE INDICATED BY THE LETTER X, WHEREAS PARENTHESIS DESIGNATE FISHES THAT WERE ONLY COLLECTED DURING OTHER INVESTIGATIONS. CONT'D.

	HABITAT					
SPECIES	1	2	3	4	5	6
Trachinotus carolinus	(X)					
Trachinotus falcatus	X					
Lutjanus griseus	X	X	(X)	X		
Lutjanus synagris	X	X				
Diapterus olisthostomus		X				
Diapterus plumieri	X	X	X	X		
Eucinostomus argenteus	X	X	X	X		
Eucinostomus gula	X	X	X			
Orthopristis chrysoptera	X	X				
Archosargus probatocephalus	X	X	(X)	X		
Lagodon thomboides	X	X	(X)	X		
Bairdielia chrysura	X	X	X	X		
Cynoscion arenarius		X		X		
Cynoscion nebulosus	X	X	X	(X)		
Leiostomus xanthurus			(X)	X		
Menticirrhus americanus	X	(X)				
Menticirrhus littoralis	X	X				
Menticirrhus saxatilis	X					
Pogonias cromis	X	(X)	(X)	X		
Sciaenops ocellata	X	(X)	X	X		
Chaetodipterus faber	X	X				
Nicholsina usta		X				
Mugil cephalus	X	X	X	X		
Mugil curema	X	X		X		
Mugil trichodon	X	X	(X)	X		
Sphyraena barracuda		(X)				
Blennius nicholsi		(X)				
Chasmodes saburrae		X				
Bathygobius soporator		(X)				
Gobionellus shufeldti		X	X			
Gobiosoma bosci		(X)				
Gobiosoma robustum		X	X	(X)		
Lophogobius cyprinoides			(X)			
Microgobius gulosus		X	X	X		
Microgobius thalassinus		X				
Trichiurus lepturus	(X)					
Sarda sarda	(X)					
Scomberomorus maculatus	X	X				
Prionotus scitulus	X	X	X			
Prionotus tribulus	X	X				
Etropus crossotus		X				
Paralichthys albigutta	X	X				
Paralichthys lethostigma		X				

APPENDIX MM - SPATIAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972, BY HABITAT: (1) BEACHES AND ADJACENT WATERS IN THE LOWER REACHES; (2) BAYS IN THE MIDDLE REACHES; (3) TIDAL STREAMS AND (4) TIDAL CANALS IN THE UPPER REACHES; (5) FRESHWATER CANALS; AND (6) FRESHWATER LAKES, PONDS, AND TEMPORARY WATERWAYS IN FAHKAHATCHEE STRAND. SPECIES TAKEN IN THE MONTHLY COLLECTIONS AT THE REGULAR STATIONS ARE INDICATED BY THE LETTER X, WHEREAS PARENTHESIS DESIGNATE FISHES THAT WERE ONLY COLLECTED DURING OTHER INVESTIGATIONS. CONT'D.

SPECIES	HABITAT					
	1	2	3	4	5	6
Achirus lineatus	X	X		(X)		
Trinectes maculatus		X	X	X		
Symphurus plagiusa		X				
Monacanthus hispidus	X	X				
Lactophrys quandricornis		(X)				
Sphoeroides nephelus	X	X	X			
Sphoeroides parvus	(X)					
Chilomycterus antillarus	X	X				
Chilomycterus schoepfi	X	X				

APPENDIX NN - TEMPORAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972. SPECIES TAKEN AT REGULAR ESTUARINE AND FRESHWATER STATIONS EACH MONTH ARE INDICATED BY THE LETTER X. PARENTHESIS DESIGNATE SPECIES THAT WERE COLLECTED DURING OTHER INVESTIGATIONS.

Species	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Carcharhinus leucas				(x)	(x)							
Carcharhinus limbatus										(x)	(x)[a]	
Negaprion brevirostris						x					x	
Sphyrna tiburo				(x)		x						
Dasyatis americana	x	x		x			x		x			
Dasyatis sabina					x	x			(x)		x	x
Gymnura micrura						x						
Aetobatus narinari						x						
Lepisosteus platyrhincus	(x)	(x)	(x)	(x)		(x)	(x)	x		(x)		
Amia calva			(x)	(x)								
Elops saurus		x	x	(x)	x	x	x		(x)	(x)		x
Megalops atlantica				(x)	(x)	(x)	(x)	(x)				
Myrophis punctatus			x				(x)		x	x		
Brevoortia patronus							(x)					
Brevoortia smithi	x	x	x	x	x	x	x	x	x	x	x	x
Harengula pensacolae	(x)	x			x	x	x	x	x	x	x	x
Opisthonema oglinum	x				x	x	x	x	x	x	x	x
Anchoa cubana			x		x							
Anchoa hepsetus	x	x	x	x	x	x	x	x	x	x	x	x
Anchoa mitchilli	x	x	x	x	x	x	x	x	x	x	x	x
Synodus foetens	x	x	x	x	x	x	x	x	x	x	x	x
Notemigonus crysoleucas	(x)	(x)	(x)	(x)								
Notropis maculatus		(x)	(x)									
Erimyzon sucetta		(x)	(x)									
Ictalurus natalis	x	(x)	x	x					x	x	x	x
Ictalurus nebulosus				(x)								
Arius felis		x	x		x		x	x	x	x	x	x
Bagre marinus				x	(x)	x			x			
Opsanus beta		x		x		x			(x)	(x)	(x)	
Gobiesox strumosus										(x)		
Ogcocephalus radiatus	x										(x)[a]	(x)[a]
Hyporhamphus unifasciatus	x				x	x	x	x	x	x	x	x
Strongylura marina	x	x	x	x	x	x	x		x	(x)	x	
Strongylura notata	x	x	x	x	x	x	x	x	x	x	x	x
Strongylura timucu			x		x	x	x	x	x	x	x	x
Tylosurus crocodilus										x	x	(x)
Adinia xenica		x				(x)		(x)			(x)	(x)
Cyprinodon variegatus			(x)	x	x	x	x	x		x	x	(x)
Floridichthys carpio	x	x	x	x	x	x	x	x		x	x	x
Fundulus chrysotus	x	(x)	(x)	(x)								
Fundulus confluentus	x	x	x	x		x	x	x	x	(x)	x	
Fundulus grandis					x	x				(x)		
Fundulus seminolis		(x)										
Fundulus similis	(x)	x	x		x		x	x		x		
Jordanella floridae	x	x	x	x		x	x		x	x	x	(x)
Lucania goodei		(x)	x	x		(x)			x	x		(x)
Lucania parva		x	x	x	x	x	x	(x)		x	x	x
Gambusia affinis	x	x	x	x		x	x	x	x	x	x	x
Heterandria formosa	x	x	x	x						x		(x)
Poecilia latipinna	x	x	x	x		x	x	x	x	x	x	x
Labidesthes sicculus	(x)	(x)					(x)					
Membras martinica	x	x			x		x	x	x	x	x	x
Menidia beryllina	x	x	x	x	x	x	x	x	x	x	x	x
Hippocampus erectus				(x)	x							
Hippocampus reidi				(x)								
Hippocampus zosterae				x		x	x	x	x	x	x	x
Syngnathus floridae			x							x		
Syngnathus louisianae	x	x	x	x	x	x	x				x	
Syngnathus scovelli	x	x	x	x	x	x	x	x	x	x	x	x
Syngnathus springeri			x									
Centropomus parallelus						(x)	(x)					
Centropomus pectinatus						(x)						

APPENDIX NN - TEMPORAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972. SPECIES TAKEN AT REGULAR ESTUARINE AND FRESHWATER STATIONS EACH MONTH ARE INDICATED BY THE LETTER X. PARENTHESIS DESIGNATE SPECIES THAT WERE COLLECTED DURING OTHER INVESTIGATIONS. CONT'D.

Species	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Centropomus undecimalis	x	x	x	(x)	x	x	x	x	(x)	x	(x)	(x)
Diplectrum formosum	(x)					x						
Epinephelus itajara									(x)	(x)	x	
Mycteroperca microlepis			(x)	(x)		x				x		
Elassoma evergladei	x	x	(x)	x								
Enneacanthus gloriosus		(x)										
Lepomis gulosus		(x)	(x)	(x)					x	(x)		x
Lepomis macrochirus		(x)	(x)	(x)		(x)	(x)	x	x	(x)		
Lepomis marginatus	(x)	(x)										
Lepomis microlophus	(x)	(x)	(x)	(x)		x	(x)			(x)		(x)
Lepomis punctatus	x	x	x	(x)			(x)			x	x	x
Micropterus salmoides	(x)	(x)	(x)			(x)	(x)					(x)
Etheostoma fusiforme		(x)										
Rachycentron canadum											(x)[a]	
Echeneis neucratoides	(x)	x								(x)	(x)	x
Caranx crysos			(x)	(x)					(x)			
Caranx hippos			(x)	(x)				x		(x)	x	
Chloroscombrus chrysurus						x	x	x		x		
Oligoplites saurus					x	x	x	x	x	x	x	x
Selene vomer						x						
Trachinotus carolinus									(x)			
Trachinotus falcatus					x		x	x	x	x	x	x
Lutjanus griseus	(x)	x	(x)	(x)		x	(x)	x	x	x	x	x
Lutjanus synagris	x				x					x	x	x
Diapterus olisthostomus	x											
Diapterus plumieri			x	x	x	x	x	x	x	x	x	x
Eucinostomus argenteus	x	x	x	x	x	x	x	x	x	x	x	x
Eucinostomus gula	x	x	x	x	x	x	x	x	x	x	x	x
Orthopristis chrysoptera		x	x	x	x	x	x	x	x	x		
Archosargus probatocephalus	x	x	x	x	x	x	x	x	(x)	x	x	x
Lagodon rhomboides	x	x	x	x	x	x	x	x	x	x	x	x
Bairdiella chrysura	x	x	x	x	x	x	x	x	x	x	x	x
Cynoscion arenarius						x	x	x	x	x		
Cynoscion nebulosus	x			(x)	x	x	x	x	x	x	x	x
Leiostomus xanthurus				x	x	x		(x)				
Menticirrhus americanus						x						
Menticirrhus littoralis		x			x			x	x	(x)		
Menticirrhus saxatilis		x		x	x							
Pogonias cromis		x	(x)	(x)		x		(x)				
Sciaenops ocellata	x	x		x		x			(x)	x	x	x
Chaetodipterus faber			x	x	x		x					
Nicholsina usta					x							
Mugil cephalus	(x)	x	(x)		x	x	x	x	x	x	x	x
Mugil curema	x	x					x	x		x		
Mugil trichodon	x	x	x	x	x	x	x	x	x	x	x	x
Sphyraena barracuda					(x)				(x)			
Blennius nicholsi	(x)											
Chasmodes saburrae						x		x	(x)	x		
Bathygobius soporator										(x)		
Gobionellus shufeldti									x	(x)	x	
Gobiosoma bosci									(x)	(x)	(x)	
Gobiosoma robustum	x	x	x	x	x	x	x	x	x	x	x	x
Lophogobius cyprinoides						(x)	(x)	(x)	(x)	(x)	(x)	(x)
Microgobius gulosus		x	x		x	x	x	x	x	x	x	x
Microgobius thalassinus	x		x						x			
Trichiurus lepturus		(x)										
Sarda sarda											(x)	
Scomberomorus maculatus			(x)				x	x	x		x	
Prionotus scitulus					x	x		x			x	
Prionotus tribulus	x								x		x	x
Etropus crossotus								x	(x)			
Paralichthys albigutta					x	x			(x)		(x)[a]	
Paralichthys lethostigma			x									

APPENDIX NN - TEMPORAL DISTRIBUTION OF FISHES COLLECTED IN TEN THOUSAND ISLANDS AND FAHKAHATCHEE STRAND, FLORIDA, 1972. SPECIES TAKEN AT REGULAR ESTUARINE AND FRESHWATER STATIONS EACH MONTH ARE INDICATED BY THE LETTER X. PARENTHESIS DESIGNATE SPECIES THAT WERE COLLECTED DURING OTHER INVESTIGATIONS. CONT'D.

Species	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Achirus lineatus						x	x		(x)	x	x	(x)
Trinectes maculatus			(x)		x	x	x	x	x	x		(x)
Symphurus plagiusa	x							x	(x)	x	x	x
Monacanthus hispidus	x		x	x		x					x	x
Lactophrys quadricornis											(x)[a]	
Sphoeroides nephelus	x	x	x	x	x	x			(x)	x	x	x
Sphoeroides parvus	x											
Chilomycterus antillarus	x				(x)	x			x		x	
Chilomycterus schoepfi	(x)			x	x	x	x	x		x	x	

[a] Collected during preliminary surveys in 1971.

APPENDIX OO - WASTE SOURCE INVENTORIES.

Broward County

1. Broward County Domestic Wastewater Source Inventory, Broward County Health Department, Fort Lauderdale, Florida, July, 1971.

2. Interim Plan for Water Quality Management, Vicinity of Broward County, Florida, Fort Lauderdale, Florida, May, 1972.

3. Broward County Wastewater Source Inventory, Broward County Health Department, Fort Lauderdale, Florida, October, 1972.

Dade County

1. Report of Waste Source Inventory and Evaluation, Dade County, Florida. Environmental Protection Agency, Southeast Region, Southeast Environmental Research Laboratory, Technical Programs, Athens, Georgia, June, 1971.

Monroe County

1. Environment and Identity - A Plan for Development in the Florida Keys. Milo Smith Associates, Inc., Planning Consultants, Tampa, Florida, June, 1970.

Palm Beach County

1. Existing Facilities Analysis, Chapter 3 of Interim Water Quality Management Plan, Palm Beach County. William M. Bishop Engineering, Inc., February, 1973.

Florida Wide

1. Municipal Waste Facilities - Region IV, U. S. Department of Health, Education and Welfare, Public Health Service Division of Water Supply and Pollution Control, Basic Data Branch, Washington, D. C., 1962.

2. Inventory of Public Sewerage Systems in Florida. Florida State Board of Health, Bureau of Sanitary Engineering, Jacksonville, Florida, 1966.

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - CHARLOTTE COUNTY.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
1. Admiralty Villas N. Beach Rd., Englewood	109		15,000	9/72 BOD 91 SS 61	a.) Extended aeration b.) Chlorination	Irrigation	9
2. Bay Vista Restaurant McCall Rd., Englewood	261		5,000	8/72 BOD 92 SS 94	a.) "MAROLF" package b.) Extended aeration	Tile drainfield	9
3. B's Restaurant Edgewater Dr., Punta Gorda			1,000		a.) "SECO" package b.) Extended aeration c.) Chlorination	Peace River	2
4. Charlotte County Country Club 3½ miles east of Punta Gorda	200		5,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
5. Charlotte County Development Authority, County Airport Industrial Park	150		7,500		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
6. East Elementary School, Punta Gorda	750		9,000	10/72 BOD 88 SS 41	a.) Extended aeration	Drainfield	9
7. El Galeon, Englewood		1,000	4,000	11/72 BOD 95.5	a.) Extended aeration b.) Chlorination c.) Sand filter	Evaporation percolation pond	9
8. Englewood Beach Condominum Englewood Beach	500		50,000	7/72 BOD 99 SS 92	a.) Contact Stabilization b.) Gas chlorination	Evaporation percolation pond	9
9. Fran & Frank's Sail-inn Charlotte Harbor			26,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Charlotte Harbor	2
10. Gasparilla Mobile Estates Placida	150		15,000	11/72 BOD 96 SS 68	a.) "DEFIANCE" package b.) Extended aeration c.) Polishing pond	Salt water canal	8
11. General Development Utilities, Inc., Toledo Blade Blvd. & Pellam Waterway, Port Charlotte	40	2,000	30,000	Engineer's estimate BOD 94	a.) Contact stabilization b.) Chlorination	Pellam Waterway to Charlotte Harbor	2
12. Gulf to Bay Trailer Park Manasota Key	30		3,000	10/72 BOD 90 SS 96	a.) Extended aeration	Lemon Bay	2
13. Harbour Heights Subdivision Highlands Rd., Punta Gorda	332	5,300	42,000	11/72 BOD 62 SS 70	a.) "IMHOFF" tank b.) Chlorination c.) Stabilization pond	DeSota Canal to Peace River	2
14. Harbour Inn Motel Tamiami Trail, Charlotte Harbor	80	2,000	8,300	9/72 BOD 98 SS 90	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Sand filters	Peace River	2
15. Harbor View Trailer Park, North of Ft. Myers			25,000	11/72 BOD 99 SS 80	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
16. Holiday Inn Travel Park Englewood			15,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
17. Hot Springs Development Charlotte Harbor			40,000		a.) Extended aeration	Charlotte Harbor	2
18. Lazy Lagoon Trailer Park Punta Gorda	300		15,000	7/72 BOD 92 SS 57	a.) Extended aeration b.) Chlorination	Shell Creek	2
19. Lemon Bay Elementary School, Englewood			9,000	7/72 BOD 91 SS 98	a.) "MAROLF" package b.) Extended aeration	Drainfield	9
20. Marylou Trailer Park Punta Gorda	342		18,000	11/72 BOD 99 SS 36	a.) "DAVCO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Peace River	2

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - CHARLOTTE COUNTY . CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
21. Fred McCullough Motel Manasota Key	24		2,000		a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Lemon Bay	2
22. B.C. Nuzum Apt. Complex Punta Gorda			6,500		a.) "AERO-JET" package b.) Extended aeration c.) Chlorination	Drainfield	9
23. Oakwater Cove Condominium Manasota Key			6,000		a.) Extended aeration b.) Chlorination c.) Sand filters	Drainfield	9
24. Palm Marina Travel Trailer Park, Cape Haze			5,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
25. Palm & Pines Trailer Park & Cottages, Punta Gorda	300		15,000	10/72 BOD 93 SS 97	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Peace River	2
26. Palm Plaza Punta Gorda	100	7,025	10,000	9/72 BOD 95 SS 93	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination		
27. Palmetto Mobile Park Charlotte Harbor	300		13,300	12/72 BOD 94 SS 96	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Charlotte Harbor	2
28. Palmetto Park Trailer Palmetto Park	300		16,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Charlotte Harbor	2
29. Park Hill Manor #1 Mobile Home Park, Burnt Store Rd., Punta Gorda	300		15,000	11/72 BOD 94 SS 98	a.) Extended aeration b.) Chlorination	Alligator Creek	2
30. Park Hill Manor #2 Mobile Home Park, Burnt Store Rd., Punta Gorda		20,000	30,000	5/72 BOD 98 SS 92	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
31. Park Point Mobile Home Park Englewood			8,000	10/72 BOD 97 SS 95	a.) Extended aeration b.) Stabilization lagoon	Lemon Bay	2
32. Pelican Harbor Mobile Home Estates, Punta Gorda	372		20,000	10/72 BOD 95 SS 77	a.) "SCHWIND" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Peace River	2
33. Pine Terrace Trailer Park Punta Gorda			15,000	12/72 BOD 99 SS 98	a.) Extended aeration b.) Chlorination	Peace River	2
34. Polynesian Palms		40,000					
35. Port Charlotte Murdock Plant, Port Charlotte			30,000	12/72 BOD 92 SS 95	a.) "DAVCO" package b.) Contact stabilization	Peace River	2
36. Port Charlotte Subdivision Port Charlotte	4,310 connections	500,000	800,000	12/72 BOD 93 SS 90	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Olman Canal to Peace River	2
37. Punta Gorda, Punta Gorda	100		10,000		a.) "IMHOFF" tank b.) Stabilization pond	Alligator Creek	2
38. City of Punta Gorda	10,000	0.75 MGD	1 MGD	9/72 BOD 98 SS 91	a.) Contact stabilization b.) Chlorination c.) Sand filters	Peace River	2
39. City of Punta Gorda Charlotte County Airport			260,000		a.) Trickling filter	Charlotte Harbor	2
40. Punta Gorda Camp Grounds Punta Gorda	198		5,000	12/72 BOD 99 SS 98	a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Alligator Creek	2

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - CHARLOTTE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
41. River Forest Mobile Home Park, Punta Gorda	700		35,000	9/72 BOD 99 SS 94	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Peace River	2
42. River Haven Mobile Home Park, Rt. 2, Punta Gorda			15,000	11/72 BOD 92 SS 97	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Alligator Creek	2
43. Rotonda West Cape Haze			25,000	10/72 BOD 98 SS 88	a.) "AER-O-FLOW" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond (Golf Course irrigation	9
44. Sea Cove Motels Punta Gorda			3,000	Engineer's estimate BOD 90	a.) "AER-O-BIC" package b.) Extended aeration c.) Chlorination	Drainfield	9
45. Seahorse Apartments Englewood			7,250	10/72 BOD 97 SS 89	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Drainfield	9
46. Shell Creek Park Camp Punta Gorda	200		10,000	11/72 BOD 99 SS 98	a.) "LIFTAIRE-3" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Shell Creek	2
47. Spanish Cove Englewood			15,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
48. Sun 'N Shade Family Campground, Punta Gorda			10,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
49. Tiki Condominium Englewood	80		4,000	9/72 BOD 95 SS 80	a.) Extended aeration b.) Chlorination	Drainfield	9
50. Windmill Village of Punta Gorda, Punta Gorda	400		17,000	9/72 BOD 98 SS 92	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Drainfield	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - COLLIER COUNTY.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
1. Avalon Elementary School Thomasson Dr., E. Naples	750		8,000	Engineer's estimate BOD 96 SS 97	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Naples Bay	5
2. Baker Carroll Point Naples	120		70,000	12/72 BOD 89 SS 98	a.) "DAVCO" package b.) Contact stabilization c.) Chlorination d.) Microstrainer	Canal to Gulf	8
3. Brookside Bowling Alley Davis Blvd., Naples			2,600	11/72 BOD 99 SS 92	a.) Extended aeration b.) Chlorination	Canal to Gulf	8
4. Capri Village Trailer Park, Cove Dr., Naples	180		10,000		a.) "AERO-JET" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
5. Captain's Table of Everglades City, Everglades City	332		34,000		a.) "DAVCO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
6. Caribbean Court Trailer Park Tamiami Trail, N. Naples	500		25,000	8/72 BOD 92 SS 75	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
7. Coconut River Estates, Airport Road, Naples			50,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
8. Collier County Administration & Court Bldg., Immokalee			5,000	12/72 BOD 91	a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
9. Collier County Government Center, E. Naples			12,000		a.) "MAROLF" package b.) Extended aeration c.) Chlorination	Haldeman Creek	5
10. Collier County Housing Authority, Immokalee	Immokalee		60,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
11. Collier-Seminole State Park, near Royal Palm Hammock	190		5,000	11/72 BOD 92 SS 93	a.) "IMHOFF" tank b.) Chlorination	Addison Bay to Big Marco Pass	6
12. Crawford Apartments Immokalee	75		7,500	12/72 BOD 75 SS 91	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Overflow to storm sewer	8
13. Duda & Sons Migrant Workers Camp, Tamiami Trail, South Naples	60		6,000	12/72 BOD 97 SS 98	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Overflow to farm ditch	8
14. East Naples Middle School Estey Dr., Naples			13,500	11/72 BOD 87 SS 81	a.) Contact stabilization b.) Stabilization pond	Evaporation percolation pond	9
15. El Rancho Mobile Village Radio Rd., Naples	250		15,000	7/72 BOD 92 SS 94	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Overflow to ditch	8
16. Enchanting Acres Trailer Park, Enchanting Acres Blvd. Naples	475		25,000	11/72 BOD 99 SS 93	a.) Contact stabilization b.) Chlorination	Haldeman Creek	5
17. Everglades City, Everglades City	1,000		100,000	7/72 BOD 89 SS 78	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Tidal canal to Chokoloskee Bay	7
18. Everglades Subdivision Ochopee			35,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
19. Florida-Vanderbilt Development Corp., Gulfshore Drive, Naples	240		12,000		a.) Extended aeration b.) Chlorination	Drainfield	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - COLLIER COUNTY. CONT'D.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
20. Forest Lake Estates, Pine Ridge Rd., Naples			25,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond (Golf course irrigation)	9
21. Glades Apt. Subdivision, Tamiami Trail, E. Naples	400		40,000		a.) "DEFIANCE" package b.) Activated sludge c.) Chlorination	Evaporation percolation pond	9
22. City of Golden Gate Subdivision, Golden Gate	3,000	70,000	300,000	11/72 BOD 94 SS 95	a.) Activated sludge b.) Chlorination c.) Stabilization pond	Gordon River	5
23. Golden Lion Motor Inn Ochopee	50 unit motel	6,900	15,000	9/72 BOD 92 SS 88	a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Borrow pit	9
24. Greystone Park, Henderson Creek, Rt. 1, Naples	292		14,000	9/72 BOD 90 SS 87	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Henderson Creek	6
25. Gulf Winds East Development, Marco Island	90		9,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
26. Harbor Lakes Co-op Club, Sandpiper St., Naples	80		6,000	11/72 BOD 87 SS 87	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
27. Harmony Shores Trailer Port Bamboo Dr., E. Naples	360		13,500	12/72 BOD 59 SS 44	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
28. Highland Elementary School, Lake Trafford Rd., Immokalee	90		9,000	9/72 BOD 87 SS 93	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Drainfield	9
29. Highland Elementary School, Lake Trafford Rd., Immokalee	750		10,000		Pond only loading of 12.5 lb. of BOD per acre per day	Evaporation percolation pond	9
30. Hitching Post Trailer Park Barefoot Williams Rd., Naples	510		40,000	11/72 BOD 99 SS 91	a.) "DEFIANCE" package b.) Contact stabilization c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
31. Holiday Manor Trailer Park Henderson Creek Dr., Naples	680		34,000	11/72 BOD 96 SS 93	a.) "DAVCO" package b.) Contact stabilization c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
32. Horne's Store & Restaurant, Tamiami Trail, Naples			2,600	10/72 BOD 95 SS 87	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Ditch	8
33. I.D. Corp. (Isle of Capri Tarpon Village, Isle of Capri			15,000		a.) Extended aeration b.) Chlorination	Drainfield	9
34. Immokalee Apartments Immokalee	480		36,000	10/72 BOD 89 SS 78	a.) Extended aeration b.) Chlorination c.) Sand filters	Drainfield	9
35. Immokalee High School, 9th St., Immokalee	135		13,500	9/72 BOD 79 SS 68	a.) "SECO" package b.) Contact stabilization c.) Chlorination d.) Stabilization pond	Drainfield	9
36. Immokalee Stockade Immokalee			10,000	9/72 BOD 97 SS 80	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Ditch	9
37. Immokalee Vegetable Harvesting & Hauling, Immokalee	100		5,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - COLLIER COUNTY. CONT'D.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
38. King's Crown Motel of Naples, Vanderbilt Beach, Naples	69	3,000	6,900	4/72 BOD 94 SS 77	a.) "MAROLF" package b.) Extended aeration c.) Chlorination	Canal to Gulf	8
39. Lake Trafford Elementary School, Lake Trafford Rd., Immokalee	750		10,000	12/72 BOD 96 SS 94	a.) "MAROLF" package b.) Extended aeration c.) Chlorination	Drainfield	9
40. Lake Trafford Marina Immokalee	100		5,000	11/72 BOD 86 SS 71	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
41. LaPlaya Motel, Gulf Shore Drive, Vanderbilt Beach, Naples	200	6,100	15,000	12/72 BOD 94 SS 93	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Tributary to Gulf	8
42. Lely Tropical Estates Subdivision, E. Naples	2,000		200,000	9/72 BOD 90 SS 69	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
43. M & E Mobile Home Park Isle of Capri				11/72 BOD 88 SS 51			
44. Marco Beach Subdivision Marco Island	2,000	123,000	200,000	9/72 BOD 97 SS 70	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Spray irrigation on Golf Course	9
45. Marco Island Inn Marco Island		4,500	10,000	11/72 BOD 94 SS 68	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
46. Marco Island Toll Bridge, Toll Plaza, Marco Island			1,650		a.) Extended aeration b.) Stabilization pond	Evaporation percolation pond	9
47. Marco Towers Apartments Isle of Capri	465	30,000	35,000	11/72 BOD 99 SS 97	a.) "DAVCO" package b.) Contact stabilization c.) Chlorination	Drainfield	9
48. McGinnis Apartment Comples, Kelly Rd., Naples	120	9,000	10,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
49. Moorhead Manor Trailer Park, Kelly Rd., Naples	400	17,000	20,000	11/72 BOD 90 SS 79	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Evaporation percolation pond, overflow to Gulf	8
50. Mozzone Mobile Home Park 12 mi. south of Naples, U.S. 41			30,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
51. City of Naples, 5th Avenue North, Naples	20,000	1.9 MGD	2.535 MGD	9/72 BOD 98 SS 98	a.) Contact stabilization b.) Chlorination	Gordon River	5
52. Naples Fruit & Vegetable Co-op (Camp Happy) Rt.2, Naples	200		20,000	11/72 BOD 94 SS 99	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
53. Naples Kampgrounds, Barefoot Williams Rd., Naples	300		15,000	11/72 BOD 96 SS 90	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
54. Naples Land Yacht Harbor Naples	500	7,500	25,000	11/72 BOD 95 SS 96	a.) Contact stabilization b.) Chlorination	Haldeman Creek	5
55. Naples Mobile Estates, Radio Rd., Naples	534		28,000	11/72 BOD 99 SS 94	a.) "DAVCO" package b.) Contact stabilization c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
56. Naples Shopping Plaza Tamiami Trail, Naples	50		10,000	11/72 BOD 98 SS 95	a.) "SECO" package b.) Extended aeration c.) Chlorination	Oyster Bay	5

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - COLLIER COUNTY. CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
57. Naples Tomato Growers, Inc. (Camp Sandy), 12 miles north of Naples	114		4,000	11/72 BOD 98 SS 92	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	SCK drainage canal	8
58. Palm River Estates Subdivision, Palm River Blvd., Naples	500		50,000	4/72 BOD 92 SS 93	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
59. Palm River Mobile Home Park, Palm River Estates, Naples		5,000	8,000	11/72 BOD 91 SS 99	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
60. Pinecrest Elementary School, 9th St., Immokalee			7,500	9/72 BOD 81 SS 82	a.) "MAROLF" package b.) Extended aeration c.) Chlorination	Drainfield	9
61. Plantation Island No. 3 Trailer Park, Everglades City	303	10,000	15,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Barron River	7
62. Port-Au-Prince Naples	400		40,000	11/72 BOD 97 SS 92	a.) Extended aeration b.) Stabilization pond	Evaporation percolation pond	9
63. Remuda Ranch Estates, Tamiami Trail South, Naples			North 35,000 South 50,000	11/72 BOD 98 SS 99	a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
64. River Bend Mobile Home Park, North of Naples			6,600		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Overflow to tidal canal	8
65. Riverwood Mobile Home Park, Isle of Capri Rd., Naples			10,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
66. Riviera Colony Mobile Home Subdivision, East Naples	800		40,000	9/72 BOD 93 SS 90	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Drainage canal	8
67. Royal Cove, U.S. 41 North, Naples			5,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
68. Royal Park Villas Condominiums, Weeks Ave., Naples	500		25,000	7/72 BOD 97 SS 99	a.) Contact stabilization b.) Chlorination	Haldeman Creek	5
69. Sandy Ridge Camp, Basso Farms, North Naples	100		10,000	4/72 BOD 76 SS 80	a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
70. Sea Gate Elementary School, Sea Gate Dr., Naples	65		6,500		a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Drainage ditch	8
71. Shadowlawn Elementary School, Shadowlawn Ave., Naples	780		8,000		a.) Septic tank b.) Sand filter	Ditch	8
72. Sorrento Villas Apartments Naples			20,000		a.) Extended aeration b.) Chlorination	Drainfield	9
73. Sunny Acres Mobile Home Park, Radio Rd., Naples			7,500		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
74. Tara Heights 8th Avenue Trailer Park, Naples	146		12,000	12/72 BOD 84	a.) "SECO" package b.) Extended aeration c.) Chlorination	Drainfield	9
75. Trafford Pine Estates Immokalee			37,500	Engineer's estimate BOD 95	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - COLLIER COUNTY. CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
76. Vanderbilt Beach Club Vanderbilt Beach, Naples	72		5,000	8/71 BOD 92 SS 97	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Wiggins Pass Waterway	5
77. Vanderbilt Towers, Vanderbilt Beach, Naples			70,000	12/72 BOD 89 SS 98	a.) Contact stabilization b.) Chlorination	River to Gulf	8
78. Villa De Marco Marco Island	200		10,000	11/72 BOD 60 SS 75	a.) Extended aeration b.) Chlorination c.) Micro filter	Marco River	6
79. Windmill Village of Naples, Mobile Home Park, Naples	475		33,000	9/72 BOD 93 SS 90	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Drainfield	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - GLADES COUNTY.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
1. Benbow Village Moore Haven	400		28,000	10/72 BOD 99 SS 85	a.) "YEOMAN" package b.) Extended aeration c.) Stabilization pond	Drainage canal	8
2. Caloosa Lodge Mobile Home Park, Glades			10,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Drainfield	9
3. Canal Front Trailer Park Moore Haven	90		5,400		a.) Extended aeration b.) Chlorination	Tile drainfield	9
4. Citrus Center Moore Haven	60		3,000		a.) "SECO" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Ditch to Caloosahatchee River	1
5. Devel's Garden Indian Reservation					a.) "IMHOFF" tank		
6. Fisheating Creek Palmdale			10,000		a.) Extended aeration b.) Chlorination	Fisheating Creek	8
7. Glades County Sugar Growers Co-op Association, Moore Haven	360		15,000	3/72 BOD 99 SS 97	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
8. Glades County Sugar Growers Co-op Plant, Moore Haven	200		5,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
9. Lykes Park Campgrounds			10,000		a.) Extended aeration b.) Chlorination	Ditch to Caloosahatchee River	1
10. Moore Haven School Moore Haven	1,000	12,000	15,000		a.) "DEFIANCE" package b.) Extended aeration	Canal to Caloosahatchee River	1
11. River Oakes Subdivision & Campground, Moore Haven			40,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
12. Shawnee farms, Clewiston			25,000	Engineer's estimate BOD 90	a.) "AER-O-FLOW" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
13. Sportsman Village Trailer Park, Moore Haven	160	7,500	10,000		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9
14. Sugar Cane Harvesting, Inc. Clewiston	120		12,000		a.) "MAROLF" package b.) Extended aeration c.) Chlorination d.) Stabilization pond	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - HENDRY COUNTY.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
1. Air Glades Air Park, Inc. Clewiston			47,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
2. City of Clewiston, S.R. 80, Clewiston	2,500	80,000	250,000	8/72 BOD 96 SS 70	a.) Contact stabilization b.) Chlorination c.) Stabilization lagoon	Canal to Lake Okeechobee	1
3. A. Duda & Sons LaBelle			5,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
4. Farm Workers Community Clewiston	275		20,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
5. Harlem Academy Clewiston			5,000	9/72 BOD 97 SS 87	a.) Extended aeration b.) Chlorination	Drainfield	9
6. Harvesters Village Clewiston	370		26,000		a.) "DAVCO" package b.) Extended aeration c.) Chlorination	Spray irrigation	9
7. Hooker Point Labor Quarters, South Bay			25,000	Engineer's estimate BOD 90	a.) "AERO-JET" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
8. City of LaBelle, Citrus St., LaBelle	600		60,000	5/72 BOD 52 SS 84	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Canal to Lake Okeechobee	1
9. LaBelle Elementary School LaBelle			2,600		a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Canal to Caloosahatchee River to Lake Okeechobee	1
10. Shumacher KOA Camp Clewiston	200		9,000		a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY.

Name & location	Population served	Flow (GPD) Avg.	Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
1. Bamboo Mobile Village, Tamiami Trail, Bonita Springs	102	1,067	5,000	9/72 BOD 96	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Leitner's Creek	4
2. Bay Shore Estates, Mobile Homes, N. Ft. Myers			20,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
3. Bayside Estates, Ft. Myers Beach			30,000	10/72 BOD 98 SS 84	a.) Contact stabilization b.) Chlorination	Land spray irrigation	9
4. Bermuda Cay Condominium Apartments, Ft. Myers							
5. Bishop Verot High School Ft. Myers			7,500	12/72 BOD 99 SS 98	a.) Extended aeration b.) Chlorination	Ditch to Caloosahatchee	3
6. Bonita Beach Apartments Bonita Springs			4,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Drainfield	9
7. Bonita Beach Trailer Park Bonita Springs			5,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
8. Bonita Egret, Bonita Beach			5,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
9. Bonita Springs Campground, Bonita Springs			17,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
10. Buccaneer Resort Inn Ft. Myers Beach			3,360	12/72 BOD 76 SS 90	a.) Extended aeration b.) Chlorination	Drainfield	9
11. Cabover Diner, 1383 Tamiami Trail, Ft. Myers			2,000	10/72 BOD 90 SS 40	a.) Extended aeration b.) Chlorination	Drainfield	9
12. Caloosa School Cape Coral			20,000	12/72 BOD 85 SS 82	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
13. Captain's Walk Condominiums, Sanibel Island	96		10,000		a.) Extended aeration b.) Chlorination	Drainfield	9
14. Carl's Sunrise Village Ft. Myers			40,000	Engineer's estimate BOD 90	a.) Contact Stabilization b.) Chlorination	Evaporation percolation pond	9
15. Carriage Village Mobile Home Park, Ft. Myers			20,000	12/72 BOD 98 SS 86	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
16. Casa Bonita Apartments Bonita Springs							
17. Century 21, North Ft. Myers	664		40,000	12/72 BOD 97 SS 97	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
18. Chateau Estates, North Ft. Myers			125,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
19. Cherry Estates, St. James			50,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
20. Colony, Sanibel Island			5,000	11/72 BOD 97 SS 93	a.) Extended aeration b.) Chlorination	Drainfield	9
21. Covered Wagon Trailer Park, Estero			15,000	12/72 BOD 99 SS 99	a.) Extended aeration b.) Chlorination	Surface irrigation	9
22. Develco (Plantation Estates) Ft. Myers			15,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Irrigation, drainfield	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
23. Diamond Head Inn, Ft. Myers Beach			5,000	12/72 BOD 99 SS 84	a.) "AER-O-BIC" package b.) Extended aeration c.) Chlorination	Drainfield	9
24. Dodrill, Rufus, Sanibel Island			25,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
25. Estero Beach Club Apartments, Ft. Myers Beach			11,250	12/72 BOD 99 SS 88	a.) Extended aeration b.) Chlorination	Drainfield	9
26. Estero Beach Club East Ft. Myers Beach			15,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Drainfield	9
27. Estero Island Inn Estero Island				12/72 BOD 99 SS 87			
28. Estero 7000, Ft. Myers Beach			100,000		a.) "MAROLF" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond & Golf course irrigation	9
29. Eventide Motel, Ft. Myers Beach			6,500	12/72 BOD 96 SS 71	a.) Extended aeration b.) Chlorination	Drainfield	9
30. Everglades Lanes, Tamiami Trail, Ft. Myers		3,400	4,370	11/72 BOD 99 SS 56	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
31. Family Estates Inc. N. Ft. Myers			25,000	Engineer's estimate BOD 97	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
32. Fiesta Village, Cypress Lakes			300,000	12/72 BOD 99 SS 81	a.) Contact stabilization b.) Chlorination	Canal to Caloosahatchee River	3
33. Flamingo Bay Inc. Ft. Myers			35,000	Engineer's estimate BOD 90 SS 90	a.) "AER-O-BIC" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
34. Florida Cities Water Company, Tropicanna Dr., Fiesta Village	1,400	94,000	150,000	Engineer's estimate BOD 95	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Lagoon to Caloosahatchee River	3
35. Florida Cities Water Company, Tropical Isles Subdivision, Ft. Myers	3,300	146,000	330,000	Engineer's estimate BOD 97	a.) Activated sludge b.) Chlorination	Caloosahatchee River	3
36. City of Ft. Myers, South of Bowling Green Subdivision, Ft. Myers	14,000	3.0 MGD	6.0 MGD	10/72 BOD 94 SS 45	a.) Contact stabilization b.) Chlorination	Caloosahatchee River	3
37. City of Ft. Myers, Raleigh St., Ft. Myers	14,000	3.0 MGD	4.0 MGD	Engineer's estimate BOD 70	a.) Trickling filters b.) Chlorination	Caloosahatchee River	3
38. Ft. Myers Beach Hotel, Ft. Myers Beach			30,000	Engineer's estimate BOD 95	a.) Contact stabilization b.) Chlorination	Drainfield	9
39. Four Seasons, N. Ft. Myers			15,000	Engineer's estimate BOD 90 SS 90	a.) "AER-O-BIC" package b.) Extended aeration c.) Chlorination	Evaporation percolation pond	9
40. Fox Trailer Park, Queen St., Ft. Myers	124	1,800	4,910	8/72 BOD 99 SS 92	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
41. Gardon Cove Mobile Home Park, Ft. Myers			12,250	7/71 BOD 93	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
42. Gasparilla Island Water Assoc., Gasparilla Island			275,000	12/72 BOD 98 SS 62	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond & Golf course irrigation	9
43. Gulf Air Trailer Park Ft. Myers			20,000	12/72 BOD 98 SS 91	a.) Extended aeration. b.) Chlorination	Drainfield	9
44. Gulf Bay Estates, Ft. Myers Beach			15,000	Engineer's estimate BOD 90 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
45. Gulf Shores Resort Condominiums, Ft. Myers Beach			20,000		a.) "AER-O-FLOW" package b.) Extended aeration c.) Chlorination	Drainfield	9
46. Holiday Inn of Ft. Myers, Beach, Ft. Myers Beach			25,000	9/72 BOD 99 SS 91	a.) "AER-O-JET" package b.) Extended aeration c.) Chlorination	Drainfield	9
47. Holiday Inn Trav-L-Park Ft. Myers			15,000	12/72 BOD 98 SS 93	a.) Extended aeration b.) Chlorination	Drainfield	9
48. Hyde Park Condominiums Ft. Myers			30,000	12/72 BOD 99 SS 85	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Drainfield	9
49. Indian Creek Mobile Home Park, Ft. Myers			25,000	Engineer's estimate BOD 90 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
50. Iona Trailer Ranch, Rt. #5, Ft. Myers	69 trailers	3,300	5,000	Engineer's estimate BOD 94	a.) Extended aeration b.) Chlorination	Canal to Caloosahatchee River	3
51. Island Beach Club Sanibel Island	260		2,600	7/72 BOD 98 SS 97	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
52. Island Inn, Sanibel Island			10,000	12/72 BOD 99 SS 89	a.) Extended aeration b.) Chlorination	Drainfield	9
53. John A. Johnson Travel Trailer Park, Golden Lake Dr., Ft. Myers	72	400	3,600	12/72 BOD 95 SS 90	a.) Extended aeration b.) Chlorination	Drainfield	9
54. Lazy Days Mobile Home Park, Ft. Myers			3,600	12/72 BOD 99 SS 99	a.) Extended aeration b.) Chlorination	Drainfield	9
55. Leasure Village Mobile Home Park, N. Ft. Myers			150,000	10/72 BOD 92 SS 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
56. Lehigh Utilities Inc., Lehigh Acres	14,800	413,000	480,000	9/72 BOD 98 SS 91	a.) Contact stabilization b.) Chlorination c.) Stabilization pond	Able Canal	3
57. Leonarde Arms Ft. Myers Beach			40,000	11/72 BOD 98 SS 95	a.) "AER-O-FLOW" package b.) Extended aeration c.) Chlorination	Drainfield	9
58. Mariner Properties Sanibel Island			30,000	Engineer's estimate BOD 95	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
59. McGregor Mobile Manor Ft. Myers			30,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
60. Mid-Island Villas Ft. Myers Beach			7,500		a.) Extended aeration b.) Chlorination	Drainfield	9
61. Mobile Land & Title Co., Bayshore Rd., Ft. Myers	800	10,000	20,000	Engineer's estimate BOD 66	a.) Contact stabilization b.) Chlorination	Drainfield	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
62. Mound Key Development Corp., Ft. Myers			51,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
63. Naples-Ft. Myers Kennel Club, Bonita Springs			40,000	12/72 BOD 99 SS 99	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
64. Nationwide Realty Sanibel Island			800,000	Engineer's estimate BOD 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
65. Neptune Inn, Beach Estates	68 motel units	5,350	7,500	12/72 BOD 99 SS 90	a.) Extended aeration	Drainfield	9
66. Oak Creek Trailer Park Bonita Springs			5,000	Engineer's estimate BOD 96 SS 99	a.) Extended aeration b.) Chlorination	Imperial River to Creek	4
67. Ohio Medical Products, Tice St., Tice			4,000	12/72 BOD 99 SS 99	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
68. Old Bridge Park Corp., N. Ft. Myers			80,000	10/72 BOD 91 SS 96	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
69. Orange Harbor Mobile Home Park, Palm Beach Blvd., Ft. Myers	325	8,000	25,000	7/72 BOD 99 SS 98	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Canal to Caloosahatchee River	3
70. Page Mobile Village, Cleveland Ave., Ft. Myers	400	15,000	30,000	Engineer's estimate BOD 83	a.) Trickling filters b.) Chlorination	Ditch to Whiskey Creek	3
71. Peaceful Pines Mobile Village, Ft. Myers			30,000	Engineer's estimate BOD 90 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
72. Pine Acres Travel Trailer Park, Pine Island			9,000	Engineer's estimate BOD 90 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
73. Pines Mobile Home Park II N. Ft. Myers			160,000	Engineer's estimate BOD 90 SS 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
74. Pink Shell Cottages Ft. Myers Beach			10,000	11/72 BOD 98 SS 95	a.) "AER-O-FLOW" package b.) Extended aeration c.) Chlorination	Drainfield	9
75. Poinsettia Mobile Home Park, Ft. Myers			50,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
76. Privateer Condominium, Estero Blvd., Ft. Myers Beach	192	5,000	10,000	11/72 BOD 96 SS 90	a.) Extended aeration b.) Chlorination	Drainfield	9
77. R & R Trailer Park Ft. Myers			30,000	Engineer's estimate BOD 90 SS 90	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
78. Red Coconut Trailer Park, Estero Blvd., Ft. Myers Beach	380	15,000	20,000	11/72 BOD 95 SS 93	a.) Extended aeration b.) Chlorination	Matanzas Pass	4
79. Jerry Ritter Trailer Park, Ft. Myers	97 trailers		10,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
80. Riverdale High School Ft. Myers			20,000	12/72 BOD 92 SS 91	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
81. River Gardens Mobile Home Park, Ft. Myers				8/72 BOD 97 SS 97			

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
82. Royal Palm Plaza Shopping Center, Ft. Myers			18,000	Engineer's estimate BOD 95 SS 95	a.) Extended aeration b.) Chlorination	Evaporation percolation pond & spray irrigation	9
83. San Carlos Subdivision San Carlos Park			150,000	7/72 BOD 99 SS 99	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond & Golf course irrigation	9
84. San Carlos Trailer Park, San Carlos Blvd., Ft. Myers	73	7,250	10,000	7/72 BOD 99 SS 94	a.) "DEFIANCE" package b.) Extended aeration c.) Chlorination	Drainfield	9
85. Sandpiper Gulf Resort, Estero Blvd., Ft. Myers	100	2,000	5,000	9/72 BOD 99 SS 97	a.) Extended aeration b.) Chlorination	Drainfield	9
86. Sanibel Center Building Sanibel Island	9 stores		3,600	12/72 BOD 99 SS 47	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
87. Serendipity South Mobile Home Park				12/72 BOD 97 SS 99			
88. Shell Harbor Inn Sanibel Island	36 apartments		5,000	11/72 BOD 99 SS 77	a.) Extended aeration b.) Chlorination	Drainfield	9
89. Sherwood Forest (Vista Village), N. Ft. Myers			50,000	Engineer's estimate BOD 93	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
90. Shibui Apartments Sanibel Island			10,000	Engineer's estimate BOD 90 SS 90	a.)"AER-O-BIC" package b.) Extended aeration c.) Chlorination	Drainfield	9
91. Skyvilla Mobile Home Park N. Ft. Myers	80	3,000	50,000	Engineer's estimate BOD 95	a.) Contact stabilization b.) Chlorination	Drainfield	9
92. South Seas Plantation Captiva Island			20,000		a.) Extended aeration b.) Chlorination	Drainfield	9
93. Southwest Florida, Bonita Springs	4,000	15,000	20,000	Engineer's estimate BOD 97	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
94. Spring Creek Village Estero			40,000	10/72 BOD 90 SS 87	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
95. Star Plaza Shopping Center N. Ft. Myers			3,500	6/72 BOD 88 SS 0	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
96. Stevens & Layton Mobile Home Park, Alva			40,000		a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
97. Sun & Fun Travel Trailer Park, Palm Beach Blvd., Ft. Myers	440	21,000	25,000	11/72 BOD 97 SS 94	a.) Activated sludge b.) Chlorination	Orange River	3
98. Sunland Training Center	1,200		250,000	12/72 BOD 94	a.) Trickling filters b.) Chlorination c.) Stabilization pond	Nine mile run to Caloosahatchee River	3
99. Swifts Trailer Park N. Ft. Myers			10,000	Engineer's estimate BOD 90 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
100. Tahiti Mobile Village Estero			30,000	6/72 BOD 99 SS 97	a.) Extended aeration b.) Chlorination	Estero River	4
101. Tamishaw Trailer Park, 2557 N. Tamiami Trail, Ft. Myers	45 trailers	3,375	5,000	8/72 BOD 99 SS 99	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
102. Tanglewood Elementary School, Tanglewood, Ft. Myers			7,500	12/72 BOD 99 SS 90	a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9

APPENDIX PP - DOMESTIC WASTE WATER INVENTORY - LEE COUNTY. CONT'D.

Name & location	Population served	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
		Avg.	Design				
103. Thunderbird Utilities, Inc. Ft. Myers			50,000	7/72 BOD 99 SS 94	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
104. Tip Top Trailer Village, Tamiami Trail, Ft. Myers	150	4,000	7,500	5/72 BOD 97 SS 79	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
105. Trailwinds Subdivision Ft. Myers			125,000	7/72 BOD 89 SS 75	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
106. Tremar Motel Apartments, First St., Ft. Myers	27 units		3,360	Engineer's estimate BOD 96	a.) Extended aeration b.) Chlorination	Drainfield	9
107. Tropicana Mobile Manor Ft. Myers	100	8,500	18,750	12/72 BOD 78 SS 67	a.) Extended aeration b.) Chlorination c.) Stabilization pond	Evaporation percolation pond	9
108. Twenty Nine Palms, Estero Blvd., Ft. Myers	60 units	14,000	15,000	Engineer's estimate BOD 90	a.) Extended aeration b.) Chlorination	Drainfield	9
109. Upriver Campground N. Ft. Myers			10,000		a.) Extended aeration b.) Chlorination	Evaporation percolation pond	9
110. Waterway Estates N. Ft. Myers			330,000	12/72 BOD 99 SS 81	a.) Contact stabilization b.) Chlorination	Caloosahatchee River	3
111. Whiskey Creek Club Estates, Ft. Myers			150,000	2/72 BOD 90 SS 40	a.) Contact stabilization b.) Chlorination	Evaporation percolation pond	9
112. Windmill Cottages Ft. Myers				10/72 BOD 95 SS 92	a.) Extended aeration b.) Chlorination		

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - CHARLOTTE COUNTY.

Name & Location	Type of waste	Influent parameters (MG/L)	Flow (GPD)		Percent removal	Type of treatment	Receiving stream	Receiving basin
			Avg.	Design				
1. Eagle's Nest Mobile Home Park, North Ft. Myers	Reverse osmosis brine							
2. Mar-Jon Laundry, Grove City	Laundry	BOD 330, DO 9.4, Ph 7.6, TS 696, SS 224		12,000	Engineer's estimate BOD 95 SS 97	a.) Trickling filter b.) Chlorination	Drainfield	9
3. Rotonda West, Rotonda West, Florida	Reverse osmosis brine							
4. Spinosa Laundry, Grove City	Laundry	BOD 300, SS 350			Engineer's estimate SS 85	a.) Trickling filter b.) Chlorination	Lemon Bay	8
5. Thrifty Mart Coin Laundry, Englewood	Laundry					a.) Port Charlotte STP		2

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - COLLIER COUNTY.

Name & location	Type of waste	Influent parameters (mg/l)	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
1. Byron Adams Laundry, 2269 Tamiami Trail, Naples	Laundry			11,000			Evaporation percolation pond	9
2. Ange Laundry, Immokalee	Laundry			12,000	Engineer's estimate BOD 93 SS 90	a.) Sand filter	Evaporation percolation pond	9
3. Chesser's Laundromat, Naples	Laundry					a.) Septic tank	Drainfield	9
4. Cochran Laundry, Naples	Laundry							
5. Cooper Slaughterhouse, Immokalee	Hog & cattle processing	BOD 2000 TSS 1000		20,000	Engineer's estimate BOD 90 SS 90	a.) Grease removal b.) Activated sludge c.) Chlorination	Irrigation	9
6. Everglades Fisheries, Everglades City	Fish & shrimp processing							
7. H.L.H. Products, Immokalee	Canned tomatoes processing					a.) Stabilization ponds		
8. Moody Laundry, Immokalee	Laundry			5,050	Engineer's estimate SS 85	a.) Trickling filter	Spray irrigation	9
9. Naples' Coin Laundry, Whitman Blvd., Naples	Laundry	BOD 140		11,300	3/72 BOD 83 SS 94	a.) Trickling filter	Drainfield	9
10. Naples Quick Clean Laundry, N. Tamiami Tr., Nap Naples	Laundry	BOD 160		11,300	4/72 BOD 86 SS 81	a.) Trickling filter	Drainfield	9
11. B.K. Popejoy Laundry, SR 29N, Immokalee	Laundry							
12. Jack Queen Laundry, Immokalee	Laundry			14,880	Engineer's estimate BOD 86	a.) Trickling filter	Evaporation percolation pond	9
13. Shell Mound Coin Laundry, Chokoloskee	Laundry	BOD 220	7,000	10,000	2/72 BOD 73 SS 74	a.) Koroseal media aeration b.) Chlorination	Bay	7
14. Wash House Laundry Immokalee	Laundry					a.) Trickling filter	Evaporation percolation pond	9
15. No name N. 4th St., Immokalle	Laundry					None		

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - GLADES COUNTY.

Name & location	Type of waste	Influent parameters (mg/1)	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
1. Glades County Sugar Growers Co-op, Moore Haven	Sugar cane processing			50,000		a.) Evaporation percolation pond		9
2. Glades County Sugar Growers Co-op, Moore Haven	Cooling water & boiler blow-down			1.1 MGD				
3. Lawhon's Laundry, Moore Haven	Laundry							
4. Moore Haven Sugar House, Moore Haven	Sugar cane processing	BOD 1500		1.0 MGD	Engineer's estimate BOD 80	a.) Ripple aeration b.) Stabilization lagoon	Canal to Lake Okeechobee	1

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - HENDRY COUNTY.

Name & location	Type of waste	Influent parameters (mg/1)	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
1. Everglades Sugar Refinery, Clewiston	Sugar cane processing	Temp. 24°C DO 0.9 COD 1052 BOD 400	220,000	140,000	Engineer's estimate BOD 97	a.) Five oxidation ponds	Farm canal to Lake Okeechobee	1
	BOD	BOD 118 TSS 106 TVS 904 DS 1098 Temp. 71°F DO 2.6 COD 736						
2. U.S. Sugar Corp, Clewiston	Sugar cane processing	Total N 7.52 Total P 2.0 Chlorides 82 Ph 6.9	3.0 MGD		Engineer's estimate BOD 96	a.) 200 acres of lagoons	Evaporation percolation ponds	9

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - LEE COUNTY.

Name & location	Type of waste	Influent parameters (mg/l)	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
1. Aewett Center Washarama, 6069 Mc-Gregor Blvd, Ft. Myers	Laundry				2/72 BOD 45 SS 67	a.) Trickling filter	Evaporation percolation pond	9
2. Bayshore Coin Laundry, 1260 N. Trail, N. Ft. Myers	Laundry					a.) Trickling filter	Evaporation percolation pond	9
3. Bob's Coin Laundry, 1120 5th St., Ft. Myers Beach	Laundry	TSS 57 TVS 796 TS 3216 Temp. 35°C DO 5.4 BOD 41 PH 7.8	2,900	6,000	2/72 BOD 92	a.) Trickling filter b.) Chlorination	Evaporation percolation pond	9
4. Busch Maytag Coin Laundry, Terry St, Bonita Springs	Laundry	BOD 402 SS 159 TS 1703 DO 6.7 PH 8.2	4,000	6,000	4/72 BOD 88 SS 10	a.) Trickling filter b.) Chlorination	Drainfield	9
5. Florida Power & Light Co., SR 80, Tice	Cooling water	$\Delta t=9^{\circ}F$ to av. conditions	Circulation of Caloosahatchee River 571.4 MGD				Caloosahatchee River	3
6. Ft. Myers Villa Laundry, 880 S. Tamiami Trail, Ft. Myers	Laundry				2/72 BOD 88 SS 89		On central sewer system	3
7. Handy Corner Laundry, Nalle Rd. & Bayshore, Ft. Myers	Laundry	BOD 224 TSS 300 Temp. 140°F	4,000	10,000	Engineer's estimate BOD 85	a.) Trickling filter b.) Chlorination c.) Stabilization pond	Drainfield	9
8. Island Shores Coin Laundry, 940 3rd St., Ft. Myers Beach	Laundry	BOD 145 SS 190 TS 1434 DO 2.7 PH 7.7	5,800	6,000	11/72 BOD 89 SS 88	a.) Trickling filter b.) Chlorination	Canal to Matanzas Pass	4
9. Island Water Association, Sanibel Island	Brine discharge	TDS 25,000 CL 10,600 SO_4 3,450		640,000		Direct discharge to Gulf		3
10. J.F. Land Coin Laundry, Pine Island	Laundry	BOD 205 TSS 198 TS 1977		15,000	3/72 BOD 86 SS 78	a.) Trickling filter b.) Chlorination	Evaporation percolation pond	9
11. Mid-Island Coin Laundry, 165 Sterling Ave., Ft. Myers Beach	Laundry	BOD 200		5,400	4/72 BOD 78 SS 51	a.) Trickling filter b.) Chlorination	Canal to San Carlos Bay	4
12. Paluck Laundry, Ft. Myers Shores	Laundry			14,880		a.) Trickling filter b.) Pond	Irrigation	9
13. Pondella Coin Laundry, Ft. Myers	Laundry	Temp. 92°F PH 7.7 DO 4.2 BOD 226 SS 228 TS 1660	Est. 5,000		1/72 BOD 71 SS 82	a.) Trickling filter	Drainfield	9
14. Prathers Laundry, 1828 Evans Ave., Ft. Myers	Laundry					City sewer		3
15. San Carlos Park Laundromat, San Carlos Park	Laundry			10,000	2/72 BOD 84 SS 54	a.) Trickling filter b.) Sand filter	Pond	9
16. Star Plaza Coin Laundry, U.S. 41 & Willis St., Nt. Ft. Myers	Laundry			13,700	4/72 BOD 68 SS 75	a.) Trickling filter	Powell Creek	3

APPENDIX QQ - INDUSTRIAL WASTE WATER SOURCES - LEE COUNTY. CONT'D.

Name & location	Type of waste	Influent parameters (mg/l)	Flow (GPD) Avg.	Flow (GPD) Design	Percent removal	Type of treatment	Receiving stream	Receiving basin
17. Tic Toc Laundromat, Jean Dr., N. Ft. Myers	Laundry							
18. Trail Dairy, N. Ft. Myers	Dairy					a.) Lagoon	Irrigation	9

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